

Analysis of the Antrim County, Michigan November 2020 Election Incident

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Abstract In November 2020, Antrim County, Michigan published unofficial election results that misstated totals in the presidential race and other contests by up to several thousand votes. Antrim subsequently issued a series of corrections, and the certified presidential results were confirmed by a county-wide hand count and a state-wide risk-limiting audit. At the request of the Michigan Secretary of State and the Department of Attorney General, I performed a forensic investigation to determine what caused the incident, verify that the errors had been corrected, assess the likelihood that similar problems could occur elsewhere, and draw lessons for election administration. I conclude that the incident in Antrim resulted from a series of operator errors, which were compounded by inadequate procedures and insufficiently defensive software engineering. Using data from the election system, I was able to reproduce the major reporting anomaly, explain how it occurred, and show that it has been corrected. However, I also uncovered other errors in Antrim County that affected small numbers of votes in specific precincts and contests and have *not* been corrected, despite the unusual attention focused on the results. One of these errors likely changed the outcome of a local contest. The incident in Antrim underscores the importance of careful execution of election procedures—including election preparation, pre-election testing, and post-election canvassing—and the need for rigorous post-election audits to surface and correct errors that might otherwise go undiscovered.

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1 Overview

Following the November 3, 2020, general election, Antrim County, Michigan published inaccurate election results, attracting national attention (e.g., [29]). Totals in the presidential race and other contests were initially misreported by up to several thousand votes [3]. Over the course of three weeks, the county restated its results four times to correct a series of errors [4][7].

The results of the presidential contest has since been confirmed by examining the paper ballots in a county-wide hand count [21] and further affirmed by a state-wide risk-limiting audit [24]. Nevertheless, the incident in Antrim raises several questions: What caused the errors? Are they evidence of a cyberattack or other foul play? Have they been fully corrected? Could similar problems affect other localities? What should be done to prevent such issues in the future?

The Michigan Secretary of State and the Department of Attorney General asked me to perform a forensic investigation of the incident in order to answer these questions. I analyzed data from Antrim County's election management system (EMS) and from the memory cards used in the county's ballot scanners. Using this data, I reconstructed the events that led to the publication of the erroneous results. I was able to reproduce the discrepancies and identify the underlying technical causes. I also electronically recounted the votes from the data on the memory cards to further check the accuracy of the final totals.

1.1 Summary of Findings

On the basis of my investigation, I draw several main findings and conclusions:

- The explanations provided by the county [2] and the Department of State [23] are correct that the inaccurate results were a consequence of human errors. However, as I will explain, the problems were more complex than initially understood. The human errors were also compounded by gaps in election procedures and their adherence and by the design of the election software.
- Although vulnerabilities in election technology are well documented (see, e.g., [11][27]), the Antrim County incident was not caused by a security breach. There is also no evidence that it was caused deliberately. While this report is not a comprehensive security review of Antrim's voting system, I note in passing some opportunities for security improvements.
- The major discrepancies in Antrim's initial results have been fully corrected. The final results match the scanner poll tapes, and there is no evidence that the poll tapes are inaccurate, except for in specific precincts where particular circumstances that I identify occurred. I explain these remaining, smaller discrepancies and determine that they affected too few votes to change the outcome of any contest but the Central Lake Village Marihuana¹ Retailer Initiative, for which the final reported outcome is likely incorrect.

¹This is the spelling used in the title of the initiative and in Michigan statutes.

- The incident in Antrim County arose due to last-minute changes to some of the ballot designs, a circumstance that is unlikely to have occurred widely in Michigan during the 2020 election. Nevertheless, the fact that the reported results were and still are in error represents a breakdown of several layers of protection that are supposed to ensure accuracy. These protections failed due to human errors on multiple levels, including mistakes by county and township staff while operating the election technology, procedural missteps while processing ballots, and the failure of the county canvassers to detect lingering discrepancies. These failings suggest a need for greater oversight of local election administration in Michigan. I also recommend several changes to election technology, training, and procedures in order to guard against a recurrence of the incident and help restore voter confidence.

1.2 Summary of the Incident

My analysis shows that the incident in Antrim County unfolded as follows:

1. In October, Antrim changed three ballot designs to correct local contests after the initial designs had already been loaded onto memory cards for the county's ballot scanners. For technical reasons, all memory cards should have been updated following the changes. Antrim used the new designs in its election management system and updated the memory cards for one affected polling place, but it did not update the memory cards for any other scanners.
2. When the changes were made, a small number of voters had already received absentee ballots reflecting the initial designs. The county mailed these voters revised ballots, but an undetermined number of the initial ballots were voted. There were procedures to ensure that each voter returned at most one ballot, but the county did not properly distinguish between the two ballot versions.
3. Townships performed logic and accuracy testing to ensure that the scanners were working and properly configured. However, the testing was not repeated after the ballot design changes, except in the one polling place where the memory cards had been updated. The county did not test loading scanner results into its election management system, nor does the state require such testing.
4. On election day, the scanners appear to have functioned normally for ballots that matched the ballot designs on their memory cards. However, they were unable to distinguish between the initial and revised ballot designs, which led to inaccurate results in specific contests in the precincts where the ballot designs had changed. In all other precincts and for all other contests, the results on the poll tapes printed by the scanners were unaffected by the changes, and there is no evidence that they are inaccurate.
5. After polls closed, the county loaded results from the memory cards into its election management system for reporting. Three cards failed to load and were entered manually from the poll tapes. The other 15 cards appeared to load normally, but 13 had not been updated after the ballot design changes.

Internally, the Dominion voting system uses a sequence of numbers to identify all available choices across all ballot designs. The scanners use these identifiers to record which candidates voters selected. This sequence was regenerated when the ballot designs were revised, which altered the identifiers used in most of the county's precincts. When memory cards that used the old identifiers were interpreted by the election management system using the new identifiers, votes were assigned to the wrong candidates, causing large errors in most contests in all but a few precincts. The election management system did not alert the operator about the problem.

6. County staff, who finished generating the result reports at 4 a.m. on November 4, apparently did not review the results closely enough to detect the obvious discrepancies before publishing them.

A few hours later, Antrim learned that the results were erroneous and took them down. Count staff manually entered totals from the poll tapes for the other affected scanners, and the county published revised results on November 5. However, they neglected to remove some of the inaccurate data that had been loaded from the memory cards, so the reported totals in some precincts were the sum of the corrected and erroneous results. The county took down the results again to correct this.

7. In one precinct, Central Lake Village, the election day poll tape showed the wrong school board race, because, although the ballot design had been changed to include the correct race, the scanner had not been updated. On November 6, Central Lake rescanned its ballots using an updated memory card, and the results were incorporated into the county's certified results, which were published that day. However, the digital records suggest that three ballots from Central Lake Village that were scanned on election day were not rescanned, for unexplained reasons, and are not included in the final results. One of these ballots, if it is actually valid, would change the outcome of the Central Lake Village Marihuana Retailer Initiative.
8. Antrim's November 6 certified results contained a large number of mistakes due to data entry errors when the results were entered manually. These errors should have been detected during the county canvass but were not. The county restated its results on November 16 to correct some of these errors and again on November 21 to correct additional errors.
9. The final certified results match the poll tapes in essentially all cases. However, my analysis shows that the poll tapes and final results are inaccurate for a few specific contests in precincts where the ballot designs changed. The largest discrepancy is in Central Lake Village, where the poll tape is inaccurate for the Central Lake Schools school board contest and State Proposal 20-1. I estimate that approximately 72 ballots are affected. Small numbers of votes may also have been affected in Mancelona Village for the Village Trustee race and in Warner Township for the Boyne Falls Public Schools Sinking Fund Millage Proposal. These effects are not large enough to change the outcome of any contest.

10. In December, the state conducted a county-wide hand count of the presidential contest that agreed with the final reported results to within 0.08%. In January, the state conducted a state-wide risk-limiting audit of the presidential contest that affirmed the reported outcome.

1.3 Organization of this Report

In Section [2] I describe Antrim County's voting system and the data from it that I examined. In Section [3] I investigate discrepancies that occurred during county-level reporting. In Section [4] I investigate discrepancies that occurred on poll tapes from individual scanners. In Section [5] I respond to the report prepared by Allied Security Operations Group. In Section [6] I state additional conclusions, and in Section [7] I offer a series of recommendations for improving election administration. My own qualifications and background are stated in Appendix [A]

2 Background

2.1 Antrim County's Election Technology

In 2017 and 2018, Michigan deployed new voting equipment [30]. County and local clerks selected from among three approved systems produced by different vendors. Antrim County adopted the Democracy Suite system produced by Dominion Voting Systems, consisting of ImageCast Precinct (ICP) ballot scanners, ImageCast X (ICX) ballot-marking devices (BMDs),² and the Democracy Suite election management system (EMS). As deployed in Antrim, the EMS consists of a single desktop PC running specialized software for election preparation and results aggregation and reporting. Antrim uses Democracy Suite version 5.5, which is federally certified by the U.S. Election Assistance Commission [31].

During a typical election, Antrim's equipment operates as follows:

1. *Election preparation.* Before the election, workers design the ballots using Election Event Designer (EED), one of several components of the EMS software [8]. They create an “election project” (a database corresponding to the election) and define the contests and choices for each precinct. EED then generates ballot designs for printing and election definition files (digital descriptions of the ballot designs) for use by the scanners and BMDs.³

Like most Michigan counties, Antrim outsources these steps to a service provider, Grand Rapids-based ElectionSource. ElectionSource sends the county an “election package”—a file containing the election project, ballot designs, election definitions, and other associated data. The county imports these into its EMS and loads the election definitions onto memory cards used by the scanners and USB sticks used with the BMDs [8].

Finally, townships load the memory cards into their scanners and perform logic and accuracy (L&A) testing. In this process, workers scan ballots with known selections and confirm that the scanners produce accurate results [13] [19].

2. *Voting and counting.* Vote counting begins on election day. In-person voters insert their ballots into the scanners, which tabulate the selections and retain the physical ballots in a ballot box. To process absentee ballots, most localities have poll workers feed them into the same scanners used for in-person voting. Other localities operate separate absent voter counting boards (“AV boards” or “AVCBs”) with dedicated scanners [15].

The scanners count votes by detecting marks in particular ballot locations called “voting targets”, which are specified by the election definition on the

²In Michigan, most voters mark ballots by hand, but each poll place also provides one or more touch-screen BMDs that voters may use to mark and print their ballots. Michigan election procedures refer to the BMDs as “voter-assist terminals” or VATs.

³Although Michigan election procedures sometime refer to election definitions as “programming” or “programs” [13] [14], in the Dominion system they are not computer programs in the sense of “software” but rather collections of data files. It is incorrect to characterize changing the election definition as a “software update.”

scanner's memory card. If the area within a voting target is darker than a set threshold, the scanner treats the target as marked. For each ballot, the scanner records which voting targets were marked on its memory card.⁴

After all ballots have been scanned, the scanner prints a "poll tape," a paper record showing the number of votes recorded for each choice. Poll workers sign the poll tape and return it, the scanner memory card, and the paper ballots (as well as other artifacts from the election) to the county [14].

3. *Reporting.* County workers use the EMS to aggregate the results using an application called Results Tally & Reporting (RTR) [9]. RTR loads vote data from the scanner memory cards and stores it in the election project database. It then generates a report containing results from the entire county. Antrim publishes these reports on its county website.
4. *Post-election verification.* Several post-election activities involve checks of the accuracy of results. Before the Board of County Canvassers certifies the results, it is supposed to compare the reported totals from the EMS to the poll tape from each scanner [17]. The paper ballots and other records are required to be securely retained, and candidates can petition for a hand recount [16]. In addition, the state audits some selected precincts to verify procedural compliance and accuracy [18]. The state also recently began conducting risk-limiting audits, in which randomly sampled ballots are inspected to confirm the accuracy of the reported outcome for particular contests [22].

2.2 The November 2020 Election in Antrim County

For the November 2020 election, Antrim used 18 scanners. Most of the 15 townships operated a single scanner, but Mancelona Township used two, and an additional two scanners were used for AV counting boards in Elk Rapids and Milton townships. Within each township, there were up to four ballot designs (for residents of villages versus unincorporated areas, or for voters within different school districts), for a total of 43 ballot designs. According to the final results, 16,044 votes were cast from among 22,082 registered voters, a turnout of 73%.

The county posted five sets of election results, dated November 4, 5, 6, 16, and 21 [3][7]. Each had widespread differences from the one before, and in some instances candidates gained or lost more than 5000 votes. The results and differences for the first four contests are summarized in Table [1].

2.3 Materials Examined for this Report

I examined a forensic image of the hard drive from Antrim County's EMS. The image was provided by the Department of Attorney General; it appears to be the image described in §F and §G of the Allied Security Operations Group (ASOG) report [1], which says ASOG collected it on December 6. I also examined forensic

⁴The ICP scanners can also store a digital image of each ballot, but this is an optional feature that was not enabled in Antrim County during the November election.

		Results published on:					Difference:			
		11/4 (a)	11/5 (b)	11/6 (c)	11/16 (d)	11/21 (e)	$b - a$	$c - b$	$d - c$	$e - d$
President	Biden	7769	7289	5960	5960	5960	-480	-1329	0	0
	Trump	4509	9783	9748	9748	9748	5274	-35	0	0
	Jorgensen	93	197	189	189	189	104	-8	0	0
	Blankenship	20	22	16	16	16	2	-6	0	0
	De La Fuente	12	8	8	8	8	-4	0	0	0
	Hawkins	20	28	28	28	28	8	0	0	0
U.S. Sen.	Peters	7863	6807	5441	5758	5758	-1056	-1366	317	0
	Squier	47	81	79	83	86	34	-2	4	3
	James	4484	9345	9340	9924	9924	4861	-5	584	0
	Willis	91	960	81	82	82	869	-879	1	0
	Dern	19	26	26	27	27	7	0	1	0
U.S. Rep.	Ferguson	7745	6603	5235	5235	5235	-1142	-1368	0	0
	Bergman	4794	10344	10292	10292	10292	5550	-52	0	0
	Boren	125	266	263	263	263	141	-3	0	0
State Rep.	Burke	7697	6143	4800	4800	5578	-1554	-1343	0	778
	Borton	4529	8772	8761	8761	9936	4243	-11	0	1175

Table 1: **Election Results.** Antrim published five results reports, two labeled unofficial (a, b) and three labeled official (c, d, e). Results and differences for the first five contests are shown here, but many others were also in error. The initial report (a) was badly incorrect due to the election definition mismatch. The second report (b) added results entered by hand from poll tapes but failed to remove all of the bad data. The third (c) fixed this, but the manual inputs contained data entry errors that were corrected in two subsequent reports (d, e).

images of the 18 compact flash memory cards used in Antrim's ICP scanners. At my request, Michigan Bureau of Elections personnel inserted each card into a Digital Intelligence USB 3.0 Forensic Card Reader (in write-blocking mode, to ensure the cards were not inadvertently modified) and used the AccessData FTK Imager application to make a complete copy of the data. Table 2 lists the hashes of these data sources.

Several kinds of data were relevant for my analysis. I will describe others later, but one of the most important was the EMS database. Democracy Suite uses the Microsoft SQL Server database engine, and data for each election project is maintained in a separate database. I extracted the database corresponding to the November 2020 election, which is stored in the files /Databases/Antrim November 2020-2020-08-03-12-38-25.mdf and .ldf. I analyzed it using Microsoft SQL Server Management Studio and purpose-built software that I wrote in Python.

In reconstructing the sequence of events, I made repeated use of log files stored in the EMS and memory cards. The election database records the actions that users perform on the election project in a table named `UserLog`. These log

Description	SHA-256 Hash of Forensic Image
<i>Computer hard drive:</i>	
County EMS	1d0d7248a0d1db99051a164766a08c895f67f358a58046102e06c20ad4785d81
<i>Ballot scanner memory cards:</i>	
Banks	784ccc460346ba85554c4798f9a1711cd73c860eaea58fa458ac241b049d2510
Central Lake	5bd0798b4a21edd390bee784519764fccc4369bdda6dbe1cafbd28c11a098bd
Chestonia	48a55e328dcf1816b42a0163a334bb4cf35fa964f1c5460ebc7a4b3fe1a2a474
Custer	1cc9a044a69567a7a38f45892b91c32a4acf631699ad1b4d9d9fbfe72e28e433
Echo	371eb895e922cd2d36cf1859c1d84df01e6fd9176132ec86c889930a20c1a8f8
Elk Rapids 1	ad69dfcadf17b5bb3a744417daae2251aca0f19ccf34af7b5e732a688a4f68f5
Elk Rapids AV	3d4ffc1d8f3ef2b336e5934f0ab98048ad0e24c96efd027f539c68239f6cdbac
Forest Home	a93c1021367b93ebc89957b5d0c5df6828c885877b2640bf4495441bbe7df474
Helena	529bc91c0d012ef4df947898d8fbde3e0d1c5f430e374080c2e52fb29d02e565
Jordan	c2fc4e0e50ca56d55fa9b211b120f319be602e357dd09fa12c14203297f3d7
Kearney	2cd3fccb9640738fb062da32d3bb1ea1e4bbafc2e97ca70d87863d12cc8fd38c
Mancelona 1	35f7d069f5556ea9aed3727a0433819b6940cb3474579cf969d2cc208324fbae
Mancelona 2	8931572f6aaeff7c7f80000ca6958da172660b9e3e8d40c073c48008593aa572
Milton 1	386390a3edfa366bb12c8263825d96b51d63a9a4711685edbd7c63fe38e2ba4a
Milton AV	255e1e27daadabfbc7ecc64d1a2c9a8e4f9cf7c65c21e9f18a2ff615dc041d09
Star	9aed3328e89ac4a98ac8ff8877a99b400f092f04a71b738b3e56579384a60379
Torch Lake	60bf46c9fb769fa6a2d238bb1d34387c0854594c9b83c72723ff306dd6abd775
Warner	8132a7e3bf7ac839152d7c6f6f68e9d1316911039241a49f23489a1c2d8e1801

Table 2: **Data Sources.** These are the hashes of the forensic images I examined. The data was collected from the EMS hard drive and 18 scanner memory cards.

entries extended back to the creation of the election project. Each memory card also contains a detailed log of events that occurred on the scanner, in a file named `slog.txt`. These logs extend back to time that each card was initialized, and the EMS stores a copy in the election database when each card is loaded.

I further analyzed the EMS by booting a copy of the hard drive in a virtual machine and interacting with the software.⁵

⁵Notably, I was able to do so without Antrim County providing any passwords. The EMS runs Windows 10, and I circumvented the Windows account passwords using a well-known technique [28]. Microsoft SQL Server Management Studio was already installed on the system, and I found that I could use it to view and edit the election databases with no additional passwords. Within the D-Suite application software, each election project is individually password protected. However, I circumvented this by creating a new project with a known password, extracting the password hash from the project’s database, and copying it into the databases for the other projects.

ASOG reports that the EMS hard drive was not encrypted [1]. This implies that an attacker with physical access to the computer could bypass password authentication entirely in the same manner that I did. However, I found no evidence that such an attack actually occurred.

3 Discrepancies in County-Level Reporting

The first part of my investigation concerns errors that were introduced in the course of aggregating and reporting results from precincts across the county, including the major discrepancies in the initial results posted on November 4. I reconstruct the events that led to the errors, explain their causes, and verify that they have been corrected. My analysis confirms that the final reported results match the results obtained by the individual scanners.

3.1 Preparations for the Election

The sequence of events that led to the reporting discrepancies began long before the election, during the process of designing the ballots. According to a timeline produced by Antrim County [2], the county received initial proofs of the ballot designs from ElectionSource on September 5. After a series of corrections, county staff approved the designs on September 18 and received a flash drive from ElectionSource containing the election package on September 29. County staff loaded the election package into the EMS, copied the election definition files for the scanners and BMDs to removable media, and distributed the media to the townships for use in the election. The memory card logs show that townships loaded the media into their scanners and BMDs and performed logic-and-accuracy testing on various dates in October.

Typically, the ballot designs and election definitions would have remained unchanged from this point on. However, according to Antrim's timeline, on October 5 and 7, the county alerted ElectionSource about errors that had been identified in three of the ballot designs, which affected parts of Central Lake, Mancelona, and Warner townships. ElectionSource applied the corrections and provided a revised election package on October 23. The election project log shows that Antrim loaded the revised election package into its EMS that day.

At this point, the county *should have* updated the removable media for all scanners and BMDs in the county to ensure that their election definitions matched the EMS's. In fact, the only scanners that were updated before election day were the two in Mancelona Township. This would prove to be a crucial mistake.

Election Packages By inspecting the EMS image, I identified an election package file with metadata indicating that it was created and last accessed on September 29. The file is located at `/Users/EMSADMIN/Desktop/Project Package/Project Package/Antrim November 2020-2020-08-03-12-38-25.package.zip`. It appears to be a backup of the first election package provided by ElectionSource on September 29. I will refer to this file as the initial election package.

I also identified an election package file with metadata indicating that it was created and last accessed on October 23. It is located at `/Users/EMSADMIN/Desktop/Project Package/Project Package/Antrim November 2020-2020-08-03-12-38-25.package.zip`. It appears to be a backup of the second election package provided by ElectionSource. I will refer to this file as the revised election package.

Ballot Design Changes I extracted the contents of the election packages. Among other files, each contains a PDF file of each ballot design. I compared the

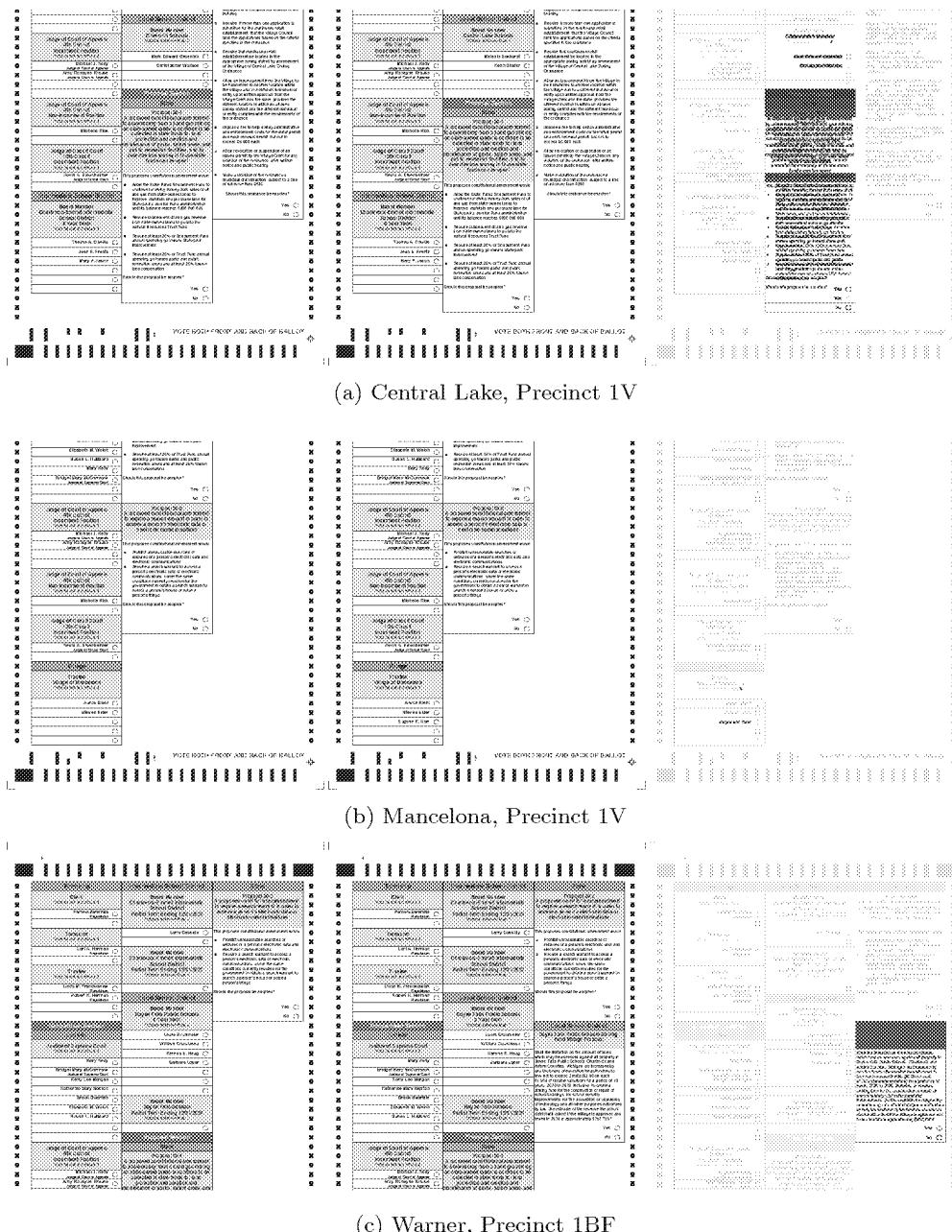


Figure 1: Ballot Design Changes. The designs of three ballots were changed between the initial election package (*left column*) and the revised package (*center column*). The differences are highlighted in red (*right column*). These changes started a chain of events that led to the publication of erroneous results.

PDF files in the initial election package to those in the revised election package and found that exactly three ballot designs differed, as illustrated in Figure 1. The differences match Antrim's description of the ballot changes 2. They are:

- *Central Lake, Precinct 1V*. On the ballot for Central Lake Village, the school board contest was corrected from the Ellsworth School District to the Central Lake School District, as shown in Figure 1a. The number of choices remained the same, but the contest changed from vote-for-two to vote-for-three, necessitating an additional write-in blank. This shifted the position of the contest below, State Proposal 20-1, down by one row.
- *Mancelona, Precinct 1V*. On the ballot for Mancelona Village, a candidate (Eugene K. Kerr) was added to the Village Trustee contest, shown in Figure 1b. The contest was also changed from vote-for-three to vote-for-two, so there was one fewer write-in blank and no change to the position of any contest.
- *Warner, Precinct 1BF*. On the ballot for part of Warner Township, a contest was added for the Boyne Falls Public Schools Sinking Fund Millage Proposal, as shown in Figure 1c. The new contest appears at the end of the last column of the last page of the ballot, so no other contest changed position.

Scanner Election Definitions The election packages also contain election definition files to be copied to each scanner's memory card. I compared the election definition files that are actually on the memory cards to those in the initial and revised election packages. The results are summarized in Table 2.

Every memory card matched either the initial or the revised election package, indicating that the election definitions on the cards were not altered after being written. Four cards matched the revised election package: Banks Township, Central Lake Township, and both precincts from Mancelona Township. The Central Lake card contains the revised election definition because it was reinitialized after the election in order to rescan the ballots. In Banks Township, the election definitions from the initial and revised packages are identical (for reasons that will become clear), so although the card was initialized using the initial election package, it happens to match the revised election package as well. All of this is consistent with Antrim's claim that the only scanners that used the revised election definitions on election day were those in Mancelona Township.

3.2 Events on Election Night

On the night of the election, November 3, the county staff began loading results into the EMS as scanner memory cards arrived from around the county. I reconstructed events that night from the EMS user log, as summarized in Table 4.

The first card was successfully loaded at 9:49 p.m. The earliest sign of trouble occurred when loading the next card, from Warner Township, at 10:31 p.m.: despite multiple attempts, the EMS refused to accept the data. The log shows that after successfully loading two further cards, at 11:03 p.m. a staffer began manually entering the Warner results from the poll tape. At 12:28 a.m., the EMS was unable to load any votes from the card from Elk Rapids Precinct 1, although there was

Hash of election definition files from:			
Scanner	Memory Card	Initial Package	Revised Package
Banks (a)	ff03cbbb51cc3a5d	ff03cbbb51cc3a5d	ff03cbbb51cc3a5d
Central Lake (b)	c00dcf4ca35ef7f6	7b8591f6740fb8f5	c00dcf4ca35ef7f6
Chestonia	f391bbd613fdc6c4	f391bbd613fdc6c4	74a7117cf151c4f
Custer	bb84f43854455a1e	bb84f43854455a1e	ba8ae12c2be863bd
Echo	0ee14f49f5791a81	0ee14f49f5791a81	34715b0f5e2f0023
Elk Rapids 1	c02565674b0f5c98	c02565674b0f5c98	20070f5cbd169c97
Elk Rapids AV	112ec69d110e5a3b	112ec69d110e5a3b	e7eec7a46e512890
Forest Home	f78c3d04faf939d3	f78c3d04faf939d3	87619945510c2734
Helena	506f34c5dafa9089	506f34c5dafa9089	df345e890f6790ac
Jordan	564abac2dddfc0d	564abac2dddfc0d	ee2ed5c613862e05
Kearney	b21d1803326105b7	b21d1803326105b7	103428ac3f693dfe
Mancelona 1 (c)	1a98842abe440234	820b4e24a3794af3	1a98842abe440234
Mancelona 2 (c)	f7261e8ce3d4e2f2	5de5f2843b9791f9	f7261e8ce3d4e2f2
Milton 1	d6707193f98ac434	d6707193f98ac434	13eafaa33fe413d1
Milton AV	f12ae9d71f3e56fe	f12ae9d71f3e56fe	b61c12678d3e9279
Star	8137bf3b0ddc8769	8137bf3b0ddc8769	77c67db8aa97ef02
Torch Lake	2f2de2a0f8bfdb8	2f2de2a0f8bfdb8	b45c508fae9aa39f
Warner	850d06f4a744f588	850d06f4a744f588	3eb6246c63c5d88a

Notes: (a) Definition is same in both packages; (b) Used initial definition Nov. 3 but rescanned Nov. 6 with revised definition; (c) Revised definition loaded before Nov. 3.

Table 3: Scanner Election Definitions. Only four of 18 scanners (Banks, Central Lake, Mancelona 1 and 2) used election definitions that matched the revised election package. Each entry shows the truncated SHA-256 hash of the election definition files. Matching hashes (*highlighted*) indicate files that are identical.

no problem with the Elk Rapids AV Board card. At 12:39 a.m., the EMS similarly was unable to load votes from the card from Milton Precinct 1 even though the Milton Township AV Board card had loaded normally. The EMS operator manually entered the results from these scanners. In all, 15 of the 18 cards loaded successfully, and three failed to load and were entered manually. The last card was loaded at 3:44 a.m., and the EMS generated the initial results report at 4:09 a.m. This report was printed, scanned, and uploaded to the county website [3].

Antrim's timeline states that it received the first reports of errors in the initial results early the next morning, around 8:15 a.m. on November 4 [2]. The county confirmed that the totals were widely inconsistent with the poll tapes, took down the published results, and began manually entering results from the poll tapes for the 15 scanners that had not already been entered manually.

3.3 How the Voting System Represents Ballots and Votes

Antrim County and the Bureau of Elections have explained that the major discrepancies in the initial results were caused by the use of mismatched election definitions on the EMS and on some of the county's scanners [23]. To verify this,

Nov. 3	21:48	<i>EMS begins loading results from tabulator memory cards.</i>	
	21:49	Chestonia Township	Card loaded successfully.
	22:31-22:38	Warner Township	Failed to load, 7 attempts.
	22:41	Banks Township	Card loaded successfully.
	22:53	Echo Township	Card loaded successfully.
	22:56	Warner Township	Final failed loading attempt.
	23:03-00:18	Warner Township	Manually entered from poll tape.
Nov. 4	00:20	Helena Township	Card loaded successfully.
	00:23	Star Township	Card loaded successfully.
	00:26	Custer Township	Card loaded successfully.
	00:28	Elk Rapids, Precinct 1	Failed to load.
	00:31	Elk Rapids, AV Board	Card loaded successfully.
	00:34	Torch Lake Township	Card loaded successfully.
	00:36	Forest Home Township	Card loaded successfully.
	00:38	Milton Township, AV Board	Card loaded successfully.
	00:38	Milton Township, Precinct 1	Failed to load.
	01:10-01:41	Elk Rapids, Precinct 1	Manually entered from poll tape.
	01:43	Central Lake Township	Card loaded successfully.
	01:48-02:04	Milton Township, Precinct 1	Manually entered from poll tape.
	02:05	Jordan Township	Card loaded successfully.
	03:36	Kearney Township	Card loaded successfully.
	03:43	Mancelona, Precinct 1	Card loaded successfully.
	03:44	Mancelona, Precinct 2	Card loaded successfully.
	03:51-04:09	<i>EMS produces unofficial results report for public distribution.</i>	

Table 4: **Election Night Timeline.** The EMS log shows that county staff worked through the night of Nov. 3–4 to load results from scanner memory cards. Three of 18 cards failed to load, and those results were entered manually from scanner poll tapes. At 4:09 a.m., the EMS produced the unofficial results report posted on Antrim’s website. Officials learned hours later that the results were erroneous.

I first determined how Democracy Suite internally represents data about ballot designs, voted ballots, and election results.

Recall that Election Event Designer (EED) is the component of the D-Suite EMS software used to generate ballot layouts and election definition files [8]. Election workers use EED to define *contests* and associated *choices* (e.g., candidates), then assign each contest to one or more *polling districts*. Some precincts consist of only one district, but others are split into multiple polling districts with different local contests, e.g., if portions of the precinct fall within different school districts. After entering this data, the EED user selects a function called “Define Ballot Structure” [8]. This causes EED to automatically generate the election definition and ballot design for each polling district, based on the defined contests.

Internally, Democracy Suite represents the structure of the ballots using a collection of database tables, as shown in Figure [2]. Each row in the **BallotManifestation** table corresponds to the ballot design used in a particular polling district; each row in the **ContestManifestation** table represents an instance of a contest appearing on a particular ballot design; and each row in the **ChoiceManifestation** table represents an instance of a choice appearing on a particular ballot design.

Every row in these tables is associated with a numeric identifier called the **internalMachineId**. When EED generates election definitions, it automatically assigns sequential **internalMachineIds** to every ballot design, to every contest, and to every choice, across all polling districts. The sequences continue from one polling district to the next, in alphabetical order. For instance, in the initial election definition, the **ChoiceManifestations** for “Central Lake Township, Precinct 1V” are assigned **internalMachineIds** 820–961 and those for “Chestonia Township, Precinct 1C7AL” (the alphabetically-next polling district) are assigned **internalMachineIds** 962–1091. The other two tables follow the same pattern.

Each memory card is loaded with a subset of the election definition data. For each ballot design used in the polling place, this data specifies the coordinates of each voting target and the **internalMachineIds** of the corresponding **ChoiceManifestation**, **ContestManifestation**, and **BallotManifestation**. The memory card also contains names of the choices and contests and other data necessary to count the votes, such as the maximum number of selections allowed in each contest and the party affiliations of the choices in contests where straight-party voting applies. This allows the scanner to tally the results itself and produce the poll tape.

The memory cards record results in two ways. First, each card contains a file with a name ending in **_TOTALS.DVD** that stores the scanner’s tallies. A second file, with a name ending in **_DETAIL.DVD**, stores the scanner’s interpretation of each ballot, which is known as a cast-vote record or **CVR**. It records whether or not the scanner detected a mark for each voting target on each contest on each ballot. These files do not contain the names of the contests and candidates. Instead, each result or selection is associated with the **internalMachineIds** of the corresponding **BallotManifestation**, **ContestManifestation**, and **ChoiceManifestation** from the scanner’s copy of the election definition.

When the EMS loads results from the memory card, it interprets these files using *its* copy of the election definition. As long as the scanner and the EMS

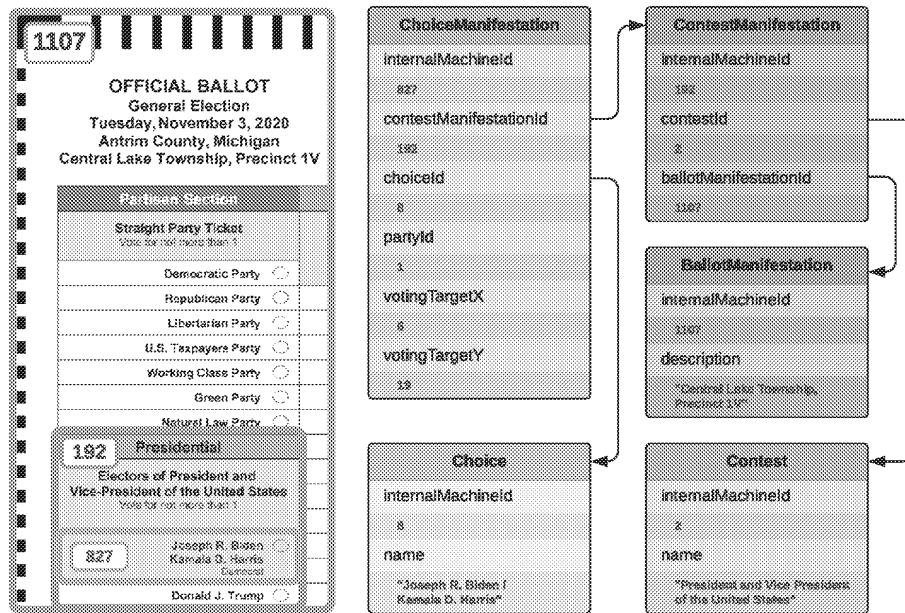


Figure 2: **Database Structure.** D-Suite represents ballot designs using a set of database tables, illustrated here in simplified form. In this example, a selection for Biden in the presidential contest on the “Central Lake Township, Precinct 1V” ballot corresponds to BallotManifestation 1107, ContestManifestation 192, ChoiceManifestation 827. The memory cards store votes using these numeric IDs.

use the same election definition, the files should be read correctly. However, D-Suite does not verify that the election definition on the memory card matches the election definition used by the EMS. When they are different—as was the case in Antrim County for scanners that weren’t updated after the ballot design changes—this can lead to inaccurate results.

3.4 Effects of the Ballot Design Changes

The election project log shows that when Antrim requested the last-minute corrections to the ballot designs, ElectionSource modified the election project in EED and regenerated the ballot layouts and election definitions. I followed the same steps, and the only indication given by the EMS software that the changes might cause problems was an easily overlooked message that “previously created election files will be unusable”, shown in Figure 3. The software did not warn that use of the old files would lead to inaccurate results. Antrim *did* use the previously deployed election definition files in 16 of 18 scanners.

Regenerating the election definitions had the effect of assigning different internalMachineIds to most voting targets throughout the county, rendering the

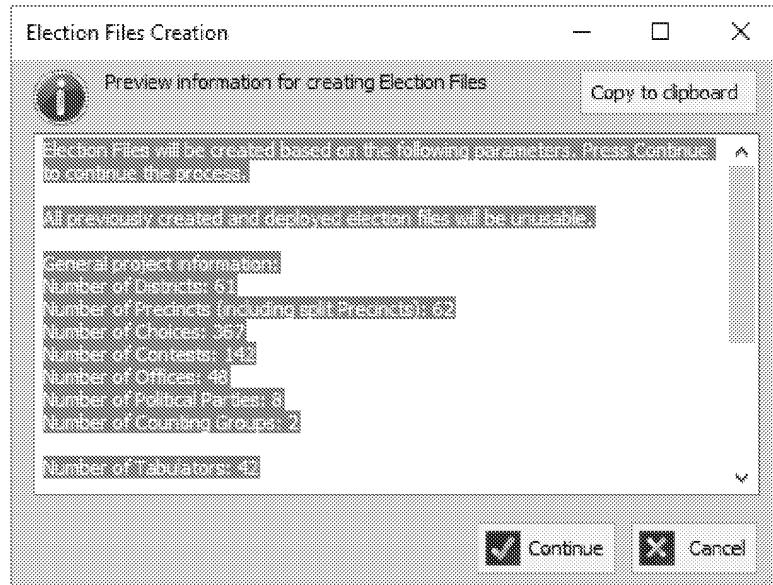


Figure 3: **Notice about Unusable Files.** When ElectionSource regenerated the election definitions, the EMS software noted that, “All previously created and deployed election files will be unusable.” In fact, previously deployed election definition files *were* used in most of Antrim County’s scanners, which led to results from those scanners being corrupted when they were loaded into the EMS.

revised election definitions incompatible with those that had already been deployed. I compared the databases from the initial and revised election projects to determine how the ballot design changes affected these identifiers.

The correction to the school board contest in Central Lake Precinct 1V required adding a write-in blank. When EED regenerated the ballot definitions to reflect this change, this insertion caused the `ChoiceManifestation` identifiers for every subsequent voting target to increase by one. That is, if the initial election project used `internalMachineId` x , the revised election project used $x + 1$. This affected all choices in later contests on the Central Lake Precinct 1V ballot and all choices in all contests for alphabetically later townships.⁶

These changes to the identifiers, coupled with the failure to update the memory cards in most scanners, caused major errors in the initial reported results. Figure 4 illustrates what went wrong. Scanners using the initial election definition recorded votes to the memory cards using the old `ChoiceManifestation` numbers. The EMS interpreted the data using the revised election definition and the new `ChoiceManifestation` numbers. Where these identifiers differed, the EMS assigned the votes to the wrong candidates. If the voter marked the first choice

⁶This explains why the election definition for Banks Township did not change: “Banks” comes before “Central Lake” in alphabetical sequence.

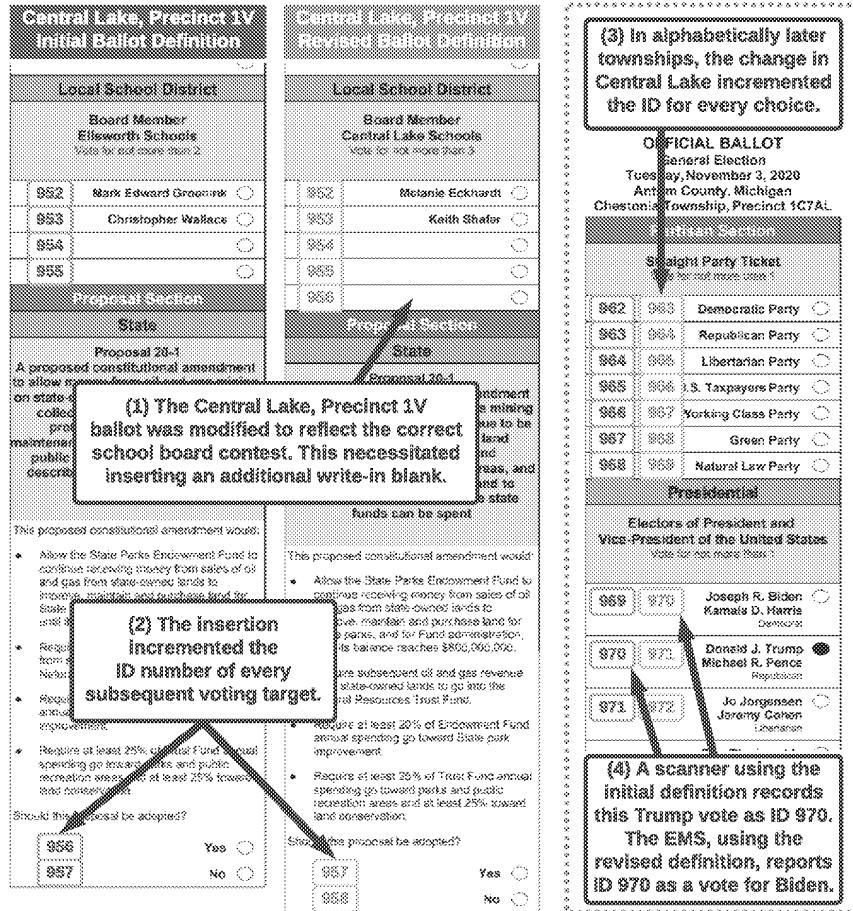


Figure 4: Explaining the Major Reporting Discrepancy. D-Suite automatically assigns sequential ID numbers to voting targets across every ballot style. Correcting the ballot design for Central Lake Village required adding a write-in blank, which increased the ID number of every subsequent voting target by 1, including all targets in alphabetically later townships. Scanners in most precincts used the initial election definition (from before the change) and recorded votes under the old ID numbers. The EMS interpreted these ID numbers using the revised election definition, causing it to assign the votes to the wrong candidates.

in an affected contest, the `ChoiceManifestation` identifier was no longer associated with the same `ContestManifestation` under the revised election definition, and the EMS silently ignored the selection. A mark for any other choice was interpreted by the EMS as a mark for the choice above it.

The ballot design changes in the other two townships were less significant for reporting. The correction in Mancelona Township left the number of choices the same, so it did not change the identifier sequence. In Warner Township Precinct 1BF, the addition of the missing Sinking Fund contest increased the identifiers of later `ChoiceManifestations` and `ContestManifestations`. However, since Warner was the last township alphabetically, and its results were entered manually on election night, these changes had no effect.

3.5 Why Cards Failed to Load

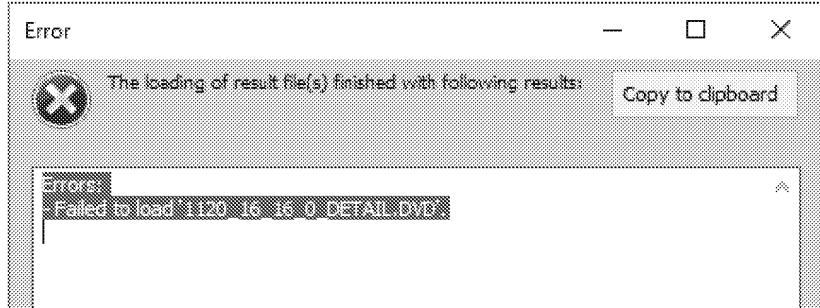
In order to understand what the EMS operator saw when loading the memory cards on election night, I followed the same steps, loading the memory card data using the D-Suite RTR application running on a copy of the EMS. The Warner Township card resulted in the generic error message shown in Figure 5a. The Elk Rapids 1 and Milton 1 cards resulted in the warning message shown in Figure 5b. The EMS reported that all other cards “loaded successfully”, as shown in Figure 5c, even when the results were corrupted by the election definition mismatch. The software gave no indication that thousands of selections were being discarded or attributed to the wrong candidates.

I investigated why the three memory cards failed to load. The EMS error log shows that the Warner Township card failed to load because of the mismatched election definitions. Unlike in the other townships where ballot designs changed, in Warner, there was a contest added to the ballot. This increased the identifiers for subsequent `ContestManifestations`, including those on the other ballot styles in Warner Township. Consequently, the Warner memory card contained votes for which the `ContestManifestation` identifiers were no longer associated with the same `BallotManifestation` under the revised election definition. The EMS apparently detected this inconsistency and refused to load the card.⁷

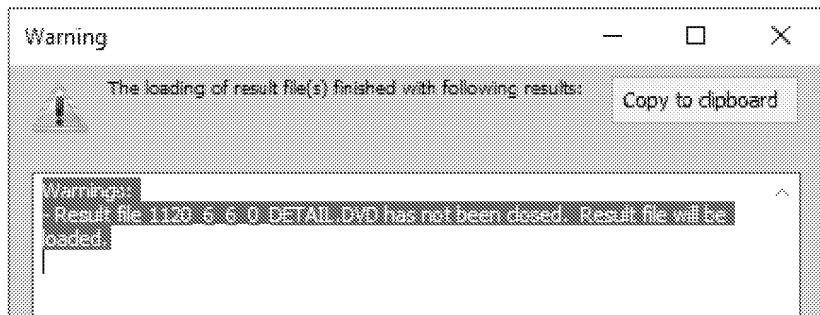
The Elk Rapids 1 and Milton 1 memory cards failed to load for a different reason: they did not contain any election results. To determine why, I examined the scanner logs on those cards. As shown in Figure 6, the logs indicate that on election day, after closing the polls and printing poll tapes, workers in these townships commanded the scanners to “re-zero” their memory cards, discarding the results and resetting the cards to a pre-election state.

Re-zeroing the cards is a significant deviation from normal election procedures. Although the poll tape contains a record of the scanner’s totals, manually entering the results is a laborious (and error-prone) process. Moreover, the data on the

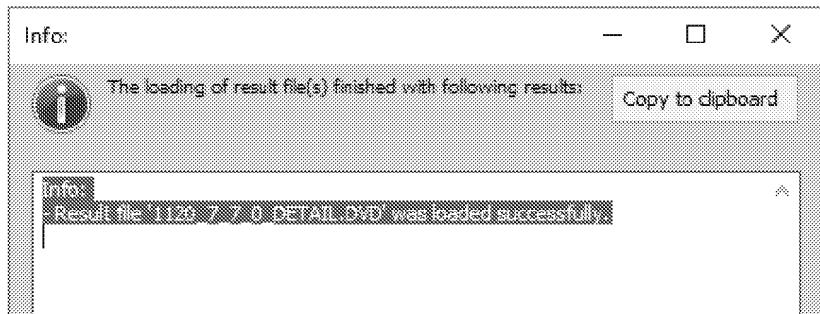
⁷This is analogous to the situation in other townships where `ChoiceManifestation` identifiers were no longer associated with the same `ContestManifestations`. However, in those cases, the EMS loaded the cards and simply ignored the affected selections.



(a) Error message displayed while loading Warner Township memory card.



(b) Warning displayed while loading Elk Rapids 1 and Milton 1 memory cards.



(c) Message displayed for all other cards, indicating loading was successful.

Figure 5: **The EMS displayed messages** indicating errors (a) or warnings (b) after attempting to load results from three scanner memory cards. For all the other memory cards, the EMS indicated that loading was successful (c), even though in most cases the results were corrupted due to the mismatched election definitions.

Nov 03/2020 06:46:02	*****
Nov 03/2020 06:46:02	* System Starting
Nov 03/2020 06:46:02	* Model Type PCOS-320C (Rev 1072)
Nov 03/2020 06:46:02	* Serial Number: AAFAJHX0109
Nov 03/2020 06:46:02	* Protective Counter: 5360
Nov 03/2020 06:46:02	* Software Version: 5.5.3-0002 #2 Fri Jul 27 09:18:31 CDT 2018
Nov 03/2020 06:46:02	* Election Project: Antrim November 2020
Nov 03/2020 06:46:02	*****
[...]	
Nov 03/2020 06:47:54	Admin chose to Open Poll
Nov 03/2020 06:47:59	Printing 1 copy of ZERO TAPE
Nov 03/2020 07:22:26	Administrator declined to print another copy of ZERO TAPE.
Nov 03/2020 07:22:26	Poll Opened for Voting Location ID 6, Tabulator ID 6
[...]	
Nov 03/2020 20:15:28	Total number of ballots = 1423.
Nov 03/2020 20:16:14	Administrator key for 'Admin' detected.
Nov 03/2020 20:16:14	Administrative Key inserted
Nov 03/2020 20:16:18	Admin chose to Close the Poll
Nov 03/2020 20:16:38	Correct passcode entered for Close.
Nov 03/2020 20:16:38	Requesting confirmation to close poll.
Nov 03/2020 20:16:49	Starting election database close poll procedure.
Nov 03/2020 20:16:49	Saving Poll-Close time.
Nov 03/2020 20:17:38	Beginning to create Total Results file.
Nov 03/2020 20:18:45	- Successfully created Total Results file '/cflash/1120_6_6_0_TOTALS.DVD'.
Nov 03/2020 20:18:46	Printing 1 copy of RESULTS TAPE
Nov 03/2020 20:21:44	Administrator chose to print another copy of RESULTS TAPE.
Nov 03/2020 20:21:45	Printing 1 copy of RESULTS TAPE
Nov 03/2020 20:24:57	Administrator chose to print another copy of RESULTS TAPE.
Nov 03/2020 20:24:57	Printing 1 copy of RESULTS TAPE
Nov 03/2020 20:29:11	Administrator chose to print another copy of RESULTS TAPE.
Nov 03/2020 20:29:11	Printing 1 copy of RESULTS TAPE
Nov 03/2020 20:31:53	Administrator declined to print another copy of RESULTS TAPE.
Nov 03/2020 20:31:53	Poll Closed for Voting Location ID 6, Tabulator ID 6
Nov 03/2020 20:32:59	Admin chose Utilities Options
Nov 03/2020 20:33:07	Admin chose to Rezero the Results.
Nov 03/2020 20:33:16	Correct passcode entered for Rezero.
Nov 03/2020 20:33:16	Start election database re-zero poll procedure.
Nov 03/2020 20:33:20	Comparing Raw Results files on primary and secondary cards...
Nov 03/2020 20:33:20	... Raw Results files match.
Nov 03/2020 20:33:20	Comparing Detail Results files on primary and secondary cards...
Nov 03/2020 20:33:20	... Detail Results files match.
Nov 03/2020 20:33:20	Comparing Write-in Image files on primary and secondary cards...
Nov 03/2020 20:33:20	... Write-in Images files match.
Nov 03/2020 20:33:21	Image Partition reset.
Nov 03/2020 20:33:21	Results re-zeroed.
Nov 03/2020 20:33:32	Admin chose to Shutdown the Unit
Nov 03/2020 20:35:23	Shutdown system.
Nov 03/2020 20:35:24	>> DvsShutdown(fast:00000000).
Nov 03/2020 20:35:24	Creating total results file
Nov 03/2020 20:35:24	Beginning to create Total Results file.
Nov 03/2020 20:35:24	- Successfully created Total Results file '/cflash/1120_6_6_0_TOTALS.DVD'.
Nov 03/2020 20:35:24	Total Results completed (rc=0)
Nov 03/2020 20:35:24	>> Shutting down AVS.

Figure 6: **Memory Cards Mistakenly Rezeroed.** Scanner logs from Elk Rapids Precinct 1 (*excerpt above*) and Milton Precinct 1 show that workers at both locations made a serious procedural error. After closing the polls and printing the poll tapes, they “rezeroed” the memory cards, discarding the digital results and resetting the cards to a pre-election state. This explains why the EMS was unable to load the two cards, forcing results to be entered manually.

memory card is the primary electronic record of the votes and an important source of evidence if the integrity of the physical ballots is called into question.

It is striking that workers in two separate polling places re-zeroed the memory cards almost simultaneously. Furthermore, this was not the first time that Antrim poll workers made this mistake. I examined the election project database from the previous election, in August 2020, which is present in the EMS image. During *that* election, the memory card for the Elk Rapids AV Board was re-zeroed and entered manually. This pattern of lapses suggests that there is a serious deficiency in the poll worker training or documentation employed in Antrim County.

These procedural errors may have contributed to the publication of incorrect results in November. Had the Elk Rapids and Milton cards loaded normally, the county-wide discrepancies would have been even more stark, making it more likely that county staff would have noticed before posting the report. Moreover, the EMS error message when loading the Warner Township card might have alerted the operator that there was a potentially serious problem, had not a superficially similar issue occurred in August for which the solution was simply to enter results manually. This appears to be an instance of “normalization of deviance”—aberrant practices coming to be considered harmless if they do not immediately cause a catastrophe—a phenomenon that has contributed to major disasters in aerospace and other industries [33].

3.6 Effects on the Presidential Contest

To further understand the effects of the mismatched election definitions, I closely examined how they impacted the initial results for the presidential contest.

The presidential candidates appeared in the same order on all ballots, beginning with Biden, Trump, and Libertarian Party candidate Jo Jorgensen. The ballots also contained a “Straight Party Ticket” option, for which the first three choices were the Democratic, Republican, and Libertarian parties. If the voter selected a party, that party’s presidential candidate would receive a vote unless the voter selected a presidential candidate from a different party or a write-in.

The initial presidential results from several scanners were unaffected by the election definition mismatch for various reasons:

- *Banks Township*. Since Banks comes first in alphabetical sequence—before the townships where the ballot designs were altered—its election definition did not change and initial results there were not affected.
- *Central Lake Township*. Although the modification to the school board race in Central Lake Village affected all subsequent contests, it occurred after every instance of the presidential contest in Central Lake Township, so the initial presidential results there were not affected.
- *Mancelona Township*. Mancelona was the only locality to have its memory cards loaded with the revised election definition before the election, so the initial results in all contests there were imported correctly by the EMS.

– *Elk Rapids 1, Milton 1, and Warner*. Since the EMS could not load these cards, results were entered manually and unaffected. (Initial results for the Elk Rapids and Milton AV Boards came from other scanners and *were* affected.)

The initial reported results from all other scanners were impacted in a consistent way, shown in Table 6. The EMS ignored selections for Biden, treated selections for Trump as selections for Biden, and treated selections for Jorgensen as selections for Trump. Other third-party candidates and write-ins were similarly shifted. The same pattern occurred with the straight-party option. Considering the effects on the straight-party and presidential selections together, the EMS ignored *most* votes intended for Biden, reported all votes intended for Trump as votes for Biden, and reported all votes intended for Jorgensen as votes for Trump.

This pattern lets us almost exactly reproduce the erroneous initial results from the final presidential results by simply shifting the totals for each candidate

	Final Results			Reproduced Error			Δ
	Biden	Trump	Jorgen.	Biden	Trump	B T	
Banks	349	756	11	(a)	349	756	0 0
Central Lake	549	906	16	(a)	549	906	0 2
Chestonia	93	197	3	←	197	3	0 0
Custer	240	521	11	←	521	11	2 0
Echo	198	392	8	←	392	8	0 0
Elk Rapids 1	784	611	5	(b)	784	611	0 0
Elk Rapids AV	202	414	12	←	414	12	0 2
Forest Home	610	753	19	←	753	19	2 0
Helena	306	431	4	←	431	4	1 0
Jordan	183	371	13	←	371	13	1 0
Kearney	471	743	16	←	743	16	1 0
Mancelona 1	276	835	20	(c)	276	835	0 0
Mancelona 2	247	646	13	(c)	247	646	0 0
Milton 1	143	478	12	(b)	143	478	0 0
Milton AV	626	543	6	←	543	6	0 0
Star	161	462	10	←	462	10	0 0
Torch Lake	462	526	7	←	526	7	1 1
Warner	60	163	3	(b)	60	163	0 0
Total	5960	9748	189		7761	4504	8 5

Precinct notes: (a) IDs not shifted; (b) Entered manually; (c) Used updated card.

Table 5: **Approximating the Erroneous Presidential Results.** A simple rule closely reproduces the erroneous initial presidential results. Working backwards from the final results (*left*), shift Trump’s votes into Biden’s column and Jorgensen’s votes into Trump’s (*right*), except for in precincts that were unaffected by the election definition mismatch for reasons noted. This yields totals that differ from the initial reported results by only 13 votes, or 0.1% (Δ).

	Voter Marks	Scanner Reads	EMS Interprets
Straight Party Ticket	Democratic	Democratic	<i>No selection</i>
	Republican	Republican	Democratic
	Libertarian	Libertarian	Republican
	U.S. Taxpayers	U.S. Taxpayers	Libertarian
	Working Class	Working Class	U.S. Taxpayers
	Green	Green	Working Class
President and Vice President	Natural Law	Natural Law	Green
	Biden	Biden	<i>No selection</i>
	Trump	Trump	Biden
	Jorgensen	Jorgensen	Trump
	Blankenship	Blankenship	Jorgensen
	Hawkins	Hawkins	Blankenship
	De La Fuente	De La Fuente	Hawkins
	Write-in	Write-in	De La Fuente

Table 6: **Misattributed Selections.** Scanners that used the initial election definition read votes for most contests correctly, but when their memory cards were interpreted by the EMS using the revised election definition, selections were attributed to the wrong candidates. This table shows the effects in the straight-party option and presidential contest, but others were similarly affected.

Voter's Selection		EMS Interpretation		Voter Intended	EMS Reported
Party	President	Party	President		
<i>No selection</i>	Trump	<i>No selection</i>	Biden	Trump	Biden
<i>X</i>	Trump	<i>X - 1</i>	Biden	Trump	Biden
Republican	<i>No selection</i>	Democratic	<i>No selection</i>	Trump	Biden
Republican	Biden	Democratic	<i>No selection</i>	Biden	Biden
<i>No selection</i>	Jorgensen	<i>No selection</i>	Trump	Jorgensen	Trump
<i>X</i>	Jorgensen	<i>X - 1</i>	Trump	Jorgensen	Trump
Libertarian	<i>No selection</i>	Republican	<i>No selection</i>	Jorgensen	Trump
Libertarian	Biden	Republican	<i>No selection</i>	Biden	Trump

Table 7: **Votes Reported for Trump and Biden.** When the EMS interpreted memory cards from most scanners that used the initial election definition, Biden received the votes intended for Trump plus those of voters who selected the Republican straight-party option but split the ticket for Biden. Trump received the votes intended for Libertarian candidate Jo Jorgensen plus those of voters who selected the Libertarian straight-party option but split the ticket for Biden.

in the affected precincts, as shown in Table 5.⁸ Biden and Trump's totals in this reconstruction differ from the initial results by only 13 votes (0.1%). This demonstrates that the election definition mismatch caused the major errors.

The small differences between the reconstruction and the actual initial results are due to unusual cases not covered by the rule above. Ballots with both the Republican straight-party option and Biden selected were *correctly* reported as votes for Biden, because the EMS misinterpreted the candidate selection as blank but also misinterpreted the party selection as Democratic. Similarly, ballots marked for the Libertarian straight-party option and for Biden were reported as votes for Trump, since the EMS misinterpreted them as having the Republican Party selected with no selection in the presidential contest. Table 7 lists all cases in which the EMS attributed correctly marked ballots to Biden and to Trump.

The final circumstance in which the election definition mismatch caused the EMS to misreport presidential votes is for certain kinds of overvotes. If the voter made *two* selections in the straight-party option or the presidential contest, this should create an overvote condition and lead to both selections being ignored. However, if one of the marks was for the Democratic Party or Biden, the EMS ignored that mark but accepted the second mark as if it had been shifted one place up the ballot, leading to a complicated set of potential errors.⁹ Such overvotes were extremely rare in Antrim County. In Section 3.9 I confirm that correcting for the full effects of the election definition mismatch, including overvotes and split-ticket votes, exactly reproduces the anomalous initial presidential results.

3.7 Anomalies in the Second Results Report

To correct the election definition mismatch, county workers manually entered results for all affected tabulators and published a second, partial set of unofficial results on November 5 [4]. However, these results were still badly erroneous, as shown in Table 1. Due to an operator error, totals for three precincts included *both* the manually entered results and the incorrect results loaded from the memory cards. This affected Custer, Echo, and the Elk Rapids AV Board. By manually examining the data in the EMS, I confirmed that the presidential results published on November 5 matched the sum of the results from the memory card and the manually entered results for the three affected scanners.

This was a simple mistake to make. From the operator's perspective, the EMS stored each version of the precincts' results as a separate table. For most precincts, there was one table with the results loaded from the memory card and a second table with the results that had been manually entered. To include tables in the results report, the operator sets them to the "published" state. After

⁸In the table, I have split out the Elk Rapids and Milton AV boards from the rest of these townships using data from the EMS, since only the AV boards were affected.

⁹For example, ballots simultaneously marked for *both* the Democratic and Republican straight-party options would be misreported as votes for Biden if the presidential contest was marked in any of the following ways: Trump; Biden and Trump; any two candidates except Biden; any combination of three or more candidates; or nobody.

Tabulator Num	Tabulator Name	File Name	Polling Location	Batch No	Court	Rejected	Count State	Adjudication	Type	CVR	Sys
2	Central Lake Tow	1120_2_2_0_DE1	Central Lake Tow	0	Election I	<input type="checkbox"/>	Rejected	NA	CVR	<input checked="" type="checkbox"/>	
2	Central Lake Tow	1120_2_2_1000	Central Lake Tow	1000	Election I	<input type="checkbox"/>	Published	NA	Manual	<input type="checkbox"/>	
3	Chestonia Towns	1120_3_3_0_DE1	Chestonia Towns	0	Election I	<input type="checkbox"/>	Rejected	NA	CVR	<input checked="" type="checkbox"/>	
3	Chestonia Towns	1120_3_3_1000	Chestonia Towns	1000	Election I	<input type="checkbox"/>	Published	NA	Manual	<input type="checkbox"/>	
4	Custer Township	1120_4_4_1000	Custer Township	1000	Election I	<input type="checkbox"/>	Published	NA	Manual	<input type="checkbox"/>	
5	Echo Township	1120_5_5_1000	Echo Township	1000	Election I	<input type="checkbox"/>	Published	NA	Manual	<input type="checkbox"/>	
6	Elk Rapids Towns	1120_6_6_0_DE1	Elk Rapids Towns	0	Election I	<input type="checkbox"/>	Rejected	NA	CVR	<input checked="" type="checkbox"/>	
6	Elk Rapids Towns	1120_6_6_1000	Elk Rapids Towns	1000	Election I	<input type="checkbox"/>	Published	NA	Manual	<input type="checkbox"/>	
100	Elk Rapids Precinct	1120_6_100_100	Elk Rapids Precinct	1000	AV Count	<input type="checkbox"/>	Published	NA	CVR	<input checked="" type="checkbox"/>	
100	Elk Rapids, Precinct	1120_6_100_100	Elk Rapids Towns	1000	AV Count	<input type="checkbox"/>	Published	NA	Manual	<input type="checkbox"/>	
7	Forest Home Tow	1120_7_7_0_DE1	Forest Home Tow	0	Election I	<input type="checkbox"/>	Rejected	NA	CVR	<input checked="" type="checkbox"/>	

Figure 7: **Operator’s View of Result Containers.** This is the EMS RTR application as it would have appeared when Antrim published its second set of unofficial results. Each line is a result container—results for a particular scanner that were either loaded from the memory card or entered manually. The operator had to click “Reject” to remove each set of erroneous memory card data. Failure to do so for the three selected rows caused large errors in the results published Nov. 5.

adding the manual results, the operator should have set the memory card results to a “rejected” state. However, the EMS log shows that this step was missed for the three scanners mentioned above. Figure 7 shows the operator’s view.

While manually entering the results, the county staff discovered that the poll tape for Central Lake Village contained the wrong school board race. This is because the scanner memory card had used the initial election definition. County staff reinitialized the Central Lake memory card using the revised election definition, and the township used it to scan its ballots again on November 6 [2].

3.8 Data Entry Errors Corrected Post-Certification

The County Board of Canvassers certified the official results late on November 6, including the results from rescanning Central Lake. However, the certified results for several precincts did not match the poll tapes, as a result of data entry errors. The errors affected about 2.6% of votes in Antrim County.

Michigan canvassing procedures call for county canvassers to compare the reported results to the poll tapes from individual machines [17], so these errors should have been caught on November 6, but they were not. Checking the poll tapes is important not only for catching data entry errors, but also as a security mechanism. If results are carefully checked, it would be impossible for an attacker to manipulate results during transmission from the polling places, or by accessing the EMS after the election, without the changes being detected. That this comparison was not correctly completed by the canvassers in Antrim County is a significant procedural breakdown that warrants further investigation.

Antrim revised its official results twice to correct the data entry errors:

1. On November 16, the county updated the official results [6] to correct Kearney Township, Precinct 1T. The EMS shows that the manually entered results had omitted the U.S. Senate and Regent of the University of Michigan contests and the number of write-ins in the presidential contest.
2. On November 21, Antrim corrected further data entry errors across several more townships. Manually entered results in Chestonia Township, Precinct 1C7AL, had omitted the results for the State Representative contest and one school board candidate. In Custer Township, Precinct 1C5BE, the number of votes for two members of the State Board of Education had been transposed. In Milton Township, Precinct 1, results had been omitted for State Representative, State Board of Education, Trustee of Michigan State University, and a variety of county and local offices. In Star Township, Precinct 1, results for State Representative and County Sheriff had been omitted. In Elk Rapids, Precinct 1T, votes for a third-party U.S. Senate candidate had been omitted, as was the number of write-in votes in the State Representative race in Precinct 1V. Also in Elk Rapids, Precinct 1V, there were typographical errors in results for County Drain Commissioner candidate Mark Stone (468 instead of 488) and Village Trustee candidate Laura Shumate (163 instead of 168).

The County published the second amended results on November 21, and they remain the final certified results [7]. The Board of State Canvassers certified Michigan's state and federal results on November 23 [12].

3.9 Confirming that All Reporting Errors have been Corrected

I conducted a series of experiments to confirm that the explanations discussed above fully account for the discrepancies between the county-level results and the poll tapes and to verify that these discrepancies have been corrected.

Rectifying the Election Definition Mismatch

First, I used the EMS software to test whether loading the memory cards using a matching election definition would produce the reported results. I restored the initial election project from the first election package, thus ensuring that the EMS was using the initial election definitions. I then used RTR to load the memory cards from all scanners that had used the initial election definition and for which electronic results were available. (That is, all but Central Lake and Mancelona 1 and 2, which scanned using the revised definition, and Elk Rapids 1 and Milton 1, where the cards were rezeroed at the polling places.) These 13 cards loaded successfully, including Warner Township's, which had failed to load on election night under the revised election definition.

Using SQL queries, I compared the results obtained in this way to the final certified results contained in the EMS database. The only discrepancy was that the Boyne Falls Public Schools Sinking Fund Millage appears in the reported results for Warner Township (with zero recorded votes) but is not present on the Warner memory card. I explain this discrepancy in Section [4].

Next, I restored the revised election project and loaded the Central Lake and Mancelona 1 and 2 memory cards under the revised election definition. I used SQL queries to compare the loaded results in this way to the final certified results contained in the EMS database. There were no discrepancies.

These results demonstrate that using a matching election definition would have prevented the reporting anomalies. They also confirm that the manually entered results from the 16 scanners for which memory card data is available do not contain further data entry errors and match the results that would have been obtained from the memory cards.

Electronically Counting Votes without the EMS

In a second experiment, I created my own software to count the presidential results from the memory cards, without relying on the software from the EMS. This provides an independent check of the accuracy of the results aggregation.

Each memory card stores cast vote records (CVRs) in a file with a name ending in `_DETAIL.DVD`. The files are encrypted using AES in CBC mode, but the encryption key and initialization vector can be retrieved from the `ElectionEvent` table in the EMS database. I decrypted the files and reverse-engineered the data format.

The CVRs are encoded using a nested data structure that stores the scanner's interpretation of each scanned ballot. Every voting target is associated with `ballotManifestation`, `contestManifestation`, and `choiceManifestation` internalMachineIds, and a boolean value that indicates whether the scanner detected that the target was marked. Each record is a sequence of `(tag, length, value)` elements terminated by the byte `0xFF`. The logical structure of the file is as follows:

```
DetailFile ::= {
    ...
    ballots SEQUENCE OF {
        ballotRecord {
            ballotManifestationId INTEGER,      -- tag 0x32
            contestsCount INTEGER,             -- tag 0x46
            ...
        },
        contests SEQUENCE OF {
            contestRecord {
                contestManifestationId INTEGER, -- tag 0x60
                choicesCount INTEGER,        -- tag 0x69
                ...
            },
            choices SEQUENCE OF {
                choiceRecord {
                    choiceManifestationId INTEGER, -- tag 0x80
                    markDetected BOOLEAN,        -- tag 0x8a
                    ...
                }
            }
        }
    }
}
```

```

    }
}
}
}
```

I wrote Python programs to extract the set of marked targets from each memory card and to count them using the election definition data from either the initial or the revised election project database. Producing a correct count requires several considerations:

1. First, the program checks the EMS database to verify that each marked `choiceManifestation` is in fact associated with the `contestManifestation` and `ballotManifestation` indicated in the CVR. Otherwise, it ignores the mark completely. This appears to match the effects of database logic within the EMS and is necessary to reproduce the erroneous results.
2. Next, the program checks for overvotes by determining whether the number of valid marks in a given contest is greater than the allowed number of selections. If so, the contest is skipped and no votes are recorded.
3. Finally, the program applies Michigan's straight-party voting rules to all partisan contests.

Using these programs, I first counted the CVRs on all cards using the revised election definition, mimicking the behavior of the EMS on election night. As expected, the presidential results were an exact match for the initial results for every scanner except Elk Rapids 1, Milton 1, and Warner, for which results were entered manually on election night, and Central Lake. (The Central Lake card was reused to scan the ballots again on November 5, and the presidential results from that card match the reported results of the rescan.) This confirms that the election definition mismatch caused the major errors during initial reporting.

Next, to undo the effects of the election definition mismatch, I used the programs to count the CVRs for each card using the election definition version found on that card, as shown in Table 3. This provides a form of confirmation of the results that does not rely on the EMS's counting and reporting logic. The presidential results exactly matched the final reported totals for every card that contained results data (i.e., all but Elk Rapids 1 and Milton 1). This further confirms that all reporting errors in the presidential contest have been corrected.

Manually Comparing the Reported Results to the Poll Tapes

As a final confirmation, I manually compared the final certified results published on Antrim County's website [\[7\]](#) to copies of the poll tapes provided by the county. I confirmed that the precinct-level results for all choices in all contests match the poll tapes, with two exceptions. The first is the Boyne Falls Public Schools Sinking Fund Millage mentioned above. The second is that the result report as published is missing pages 47–48, which contain the Banks Township Trustee contest and the Central Lake Township Supervisor contest. Other pages are out of order or duplicated, so this omission is likely the result of human error while scanning the report. For all other contests, this confirms that the anomalies in county-level reporting have been corrected and the results match the poll tapes.

4 Discrepancies in the Scanner Poll Tapes

The analysis in Section 3 firmly establishes that the major reporting anomalies on election night resulted from the use of different election definitions in the county EMS that in most of the county's scanners. I also showed that the errors introduced during county-wide reporting have been corrected, and the final reported results match the poll tapes produced by the individual scanners.

However, the poll tapes themselves contain errors that affect smaller numbers of votes in specific contests and precincts. These errors have a different pattern than the major reporting anomalies. In most precincts, the design of the printed ballots was not changed, and so the individual scanners counted normally whether they were using the initial or the revised election definition. But ballot designs *were* changed in parts of three townships—Central Lake, Mancelona, and Warner—and the changes led to a number of errors in the poll tapes for these localities. In this section, I investigate what caused the poll tape errors, determine the effects, and show that certain errors remain uncorrected in the final official results.

4.1 Logic and Accuracy Testing

Logic and accuracy testing (L&A testing) is an important pre-election procedure that is intended to check that polling place equipment produces accurate poll tapes. In order to produce accurate counts, the scanners need to use election definitions that are properly prepared and that match the design of the ballots being scanned. Correctly performed L&A testing checks both. Although L&A testing cannot protect against sophisticated attacks on the voting equipment [10], it *should* prevent both accidental and deliberate scanner configuration errors.

Michigan election procedures require L&A testing of all scanners and voter-assist terminals [19]. Workers use a “test deck,” a set of ballots marked in advance so that all voting targets are tested and the correct results are known. After scanning the test deck, they verify that the poll tape matches the expected results. Any deviations are a potential indication of an error in the election definition.

I examined the scanner logs from the memory cards to determine whether L&A testing occurred.¹⁰ Every scanner was tested before the election, as shown in Table 8. Notably, both Mancelona Township cards were tested after the cards were updated with the revised election definition. Although the Central Lake scanner was tested before election day, it was not tested again after the card was reinitialized with the revised election definition prior to the November 6 rescan.

Despite the fact that every scanner was tested prior to election day, the testing was not successful at flagging some clear problems. The poll tapes produced during testing in Central Lake and Warner townships reflected the initial ballot designs, so they contained an incorrect contest and were missing a contest, respectively. By the time the testing occurred, the county was aware of the ballot design errors, and so presumably were the townships. The workers who performed the

¹⁰The original log for Central Lake was erased when the memory card was reinitialized for the November 6 rescan. I examined a copy of the log from the EMS database.

Scanner	L&A Test Dates	Number of Test Ballots
Banks	October 22	50, 256
Central Lake	October 23	128
Chestonia	October 19	262
Custer	October 24	256
Echo	October 14 and 21	192; 192
Elk Rapids 1	October 14 and 21	64, 64; 128
Elk Rapids AV	October 14, 21, and 29	64, 64; 128; 8
Forest Home	October 23	192
Helena	October 20	64
Jordan	October 28	192
Kearney	October 27	192
Mancelona 1	October 24	126
Mancelona 2	October 24	127
Milton 1	October 17	64, 64
Milton AV	October 17	64
Star	October 20	64
Torch Lake	October 21	64, 64, 64
Warner	October 20	64, 192

Table 8: Logic & Accuracy Testing. L&A testing checks that scanners produce correct poll tapes when tallying a “test deck” of ballots with known selections. Every memory card used on election day was tested at least once. In Central Lake and Warner, the tests should have detected errors in the poll tapes but did not.

testing must have either ignored these discrepancies or failed to review the test decks and poll tapes carefully enough to spot them. Had the townships reacted to these errors by updating their election definitions, it would have prevented some (but not all) of the residual anomalies described in this section.

Michigan only requires L&A testing at the township level. There is no procedural requirement to test loading results from scanner memory cards into the EMS to confirm that the EMS produces reports that match the poll tapes. The EMS logs confirms that no such testing was conducted in Antrim County. Had the county tested loading the memory cards into the EMS, it is likely that the election definition mismatch would have been detected, and the county-level reporting anomalies might have been averted.

4.2 Use of Outdated Ballots and Election Definitions

The three townships where ballot designs were altered scanned ballots a total of four times: once in Warner using the initial election definition, once in Mancelona using the revised election definition, and twice in Central Lake using the initial and then the revised election definition. Two factors led to inaccurate poll tapes during these scans. First, the scans that used initial election definitions necessarily produced results that omitted contests or candidates that were added when the

ballot designs were revised. Second, some of the paper ballots that were scanned themselves used the outdated designs.

The last-minute ballot design changes in Central Lake, Mancelona, and Warner occurred after absentee voting had already begun. For instance, according to Antrim County, 224 absentee ballots for Central Lake Village had been sent to voters before the change. The county asserts that these voters were later sent corrected ballots, but, although there were procedures to ensure that voters did not return more than one ballot, there was apparently no mechanism in place to ensure that only revised ballots were used or to separate initial and revised ballots upon receipt.¹¹ Townships *should* have transcribed votes from ballots that used the initial design onto fresh ballots using the revised design, but did not. Instead, they scanned the initial and revised ballots together as single batches. The scanners had no way to distinguish between the two ballot versions, so this led to inaccurate tallies whether the initial or revised election definition was used.

4.3 Effects in Warner Township

The ballot for Warner Township Precinct 1BF was altered to add a missing contest, the Boyne Falls Public Schools Sinking Fund Millage, as shown in Figure [1c]. The contest was added to the end of the last column of the ballot, so no other contests or voting targets were affected. However, as the Warner scanner's election definition was never updated, the votes in this contest were not read or reported by the scanner at all. The contest does not appear on the scanner poll tape and is not recorded on the memory card.

Only a small number of Warner Township voters live in the Boyne Falls School District and were eligible to vote in the Sinking Fund contest. The final results show that there were three registered voters and three ballots cast, but no "Yes" or "No" votes were recorded in the Sinking Fund contest. Some voters may have left the contest blank, and any who voted absentee using the initial ballot design would have returned ballots that lacked the contest entirely. Therefore, we can conclude that between zero and three votes in the Sinking Fund contest were never counted. This is too few votes to affect the outcome of the contest.

4.4 Effects in Mancelona

The Mancelona Precinct 1V (Mancelona Village) ballot was revised to add a missing candidate for Village Trustee, Eugene K. Kerr. The contest also changed from vote-for-three to vote-for-two, so the effect was that Kerr replaced a write-in blank, and no other contests or choices changed position, as shown in Figure [1c].

Mancelona's scanners used the revised election definition, but some absentee voters may have returned ballots that used the outdated ballot design. If any of

¹¹There is also no indication that Central Lake, Mancelona, or Warner Township updated its voter-assist terminals (VATs) to reflect the revised ballot designs. If they did not, voters who used the VATs would have been presented with outdated ballots. However, according to Antrim County, no voters used the VATs in the affected townships.

these voters selected the first write-in blank, the scanners misinterpreted the vote as a vote for Kerr. Likewise, if any of these voters selected three candidates, the votes would have been unexpectedly discarded as overvotes. The data I examined is insufficient to determine how many votes, if any, were affected by these cases. However, they are likely uncommon, and the Village Trustee contest was decided by a large margin, so they are unlikely to have altered the outcome.

4.5 Effects in Central Lake

The effects of the changes in Central Lake were considerably more complicated. Figure 1a shows how the ballot design in Central Lake Precinct 1V (Central Lake Village) was altered to correct the school board contest from Ellsworth Schools to Central Lake Schools. This changed the name of the contest and candidates and also the allowed number of selections, which increased from two to three. The increase necessitated an additional write-in blank, which shifted the position of the contest below, State Proposal 20-1, down by one row.

Central Lake used the initial election definition on election day, and results loaded from the memory card were included in the first unofficial results. The township then rescanned using the revised election definition on November 6, producing a second poll tape, which was manually entered as part of the certified results. Results in the three contests affected by the ballot design change differed dramatically between the two scans, as shown in the poll tape excerpts in Figure 8.

Both sets of scan results are partially incorrect. This is because although most of the ballots used the revised ballot design, a substantial minority used the initial ballot design. Those that used the revised design were scanned incorrectly during the first scan, and those that used the initial design were scanned incorrectly during the second scan. I explain the nature of these errors below.

Errors in the Election Day Scan

Central Lake used the initial election definition on election day, but most voted ballots used the revised ballot design. This had several consequences for the accuracy of the poll tape.

First, the school board contests were affected as follows:

1. Central Lake Village votes were incorrectly included in the Ellsworth Schools contest. For ballots that used the initial design, which incorrectly showed the Ellsworth contest, votes were counted towards this contest even though the voters were not eligible to vote in it. For ballots that used the revised design, which showed the correct Central Lake Schools contest, votes were incorrectly tabulated for the candidates in the equivalent ballot positions in the Ellsworth contest. Thus, Groenink received Eckhardt's votes on the poll tape, and Wallace received Shafer's votes.
2. On ballots that used the revised design, any write-in selections that used the third write-in blank were completely ignored, since there was no voting target in that position in the initial ballot design. These were not reflected in the election-day poll tape or on the memory card.

School Board Member for Central Lake Schools (3)		School Board Member for Central Lake Schools (3)	
Melanie Eckhardt:	519	Melanie Eckhardt:	852
Keith Shafer:	525	Keith Shafer:	846
Write-in:	24	Write-in:	112
Total Votes:	1068	Total Votes:	1810

School Board Member for Ellsworth Schools (2)		School Board Member for Ellsworth Schools (2)	
Mark Edward Groenink:	333	Mark Edward Groenink:	3
Christopher Wallace:	326	Christopher Wallace:	3
Write-in:	10	Write-in:	0
Total Votes:	653	Total Votes:	6

State Proposal 20-1 (1)		State Proposal 20-1 (1)	
Yes:	774	Yes:	1083
No:	598	No:	296
Total Votes:	1282	Total Votes:	1289

(a) Election Day Scan (Nov. 3)

(b) Second Scan (Nov. 6)

Figure 8: **Central Lake Poll Tapes.** Central Lake scanned twice: on election day using the initial election definition and on November 6 using the revised election definition. The poll tapes from the second scan showed large differences in three contests, excerpted above, due to the changes in the election definition. Although the second scan is closer to the correct results, my analysis shows that the Central Lake School Board and State Proposal 20-1 results are still in error.

3. The revised ballot design allowed up to three votes for school board. However, if a voter selected three candidates, other than by using the third write-in blank, the scanner ignored all the selections as if the contest had been overvoted, and they were not included in the poll tape.

The poll tapes in Figure 8 reflect these errors. The numbers shown for each school board contest are the total number of votes received in all precincts in Central Lake: 1V (Central Lake Village), 1CENT (Central Lake Schools), and 1ELS (Ellsworth Schools, which has only a small number of voters). In the first scan, school board votes from Precinct 1V were included in the Ellsworth totals, and in the second scan, they were included in the Central Lake totals. Thus the second scan total for each of the two Central Lake Schools candidates approximately equals the sum of the votes in the first scan for the Central Lake and Ellsworth candidates in the equivalent position.

The election night results from the EMS were also wrong for these contests, but in a different way than the poll tapes. The memory card used the initial election definition, but the EMS used the revised election definition. Both election definitions used the same `contestManifestation` identifier for the Central Lake Village school board contest and the same `choiceManifestation` identifiers values for the four voting targets that were present in both ballot designs. Thus, ballots that used the revised ballot design and only included marks among the first four choices were reported *correctly* by the EMS. Those on which the fifth choice (the third write-in blank) was selected were interpreted incorrectly, since the scanners did not record marks for this target. Ballots that used the initial design (with the Ellsworth School contest) were also interpreted incorrectly by the EMS, with votes counted towards the Central Lake Schools candidates in equivalent positions.

The first Central Lake poll tape also contains incorrect results for State Proposal 20-1. In the revised ballot design, the voting target for “Yes” is in the same position as the target for “No” was in the old design, and the target for “No” is in a position that was unused in the old design, as depicted in the left half of Figure 9. In the first scan, the scanner used the initial election definition. This caused it to misread Proposal 20-1 selections for ballots that used the revised design. For these ballots, the poll tape reported “Yes” votes as “No” and failed to record “No” votes at all. Ballots using the initial design were read correctly.

When the EMS loaded the memory card from the first scan, Proposal 20-1 votes were additionally affected by the election definition mismatch. The net effect was that *both* ballots using the initial design that were marked for “No” and ballots using the revised design that were marked for “Yes” were reported by the EMS as votes for “Yes,” and all other selections were discarded.

Errors in the November 6 Scan

Central Lake completed a second scan on November 6, using the revised election definition. This time, ballots that used the revised design were counted correctly, but ballots from Central Lake Village that used the initial design were partially misinterpreted. The school board race was affected as follows:

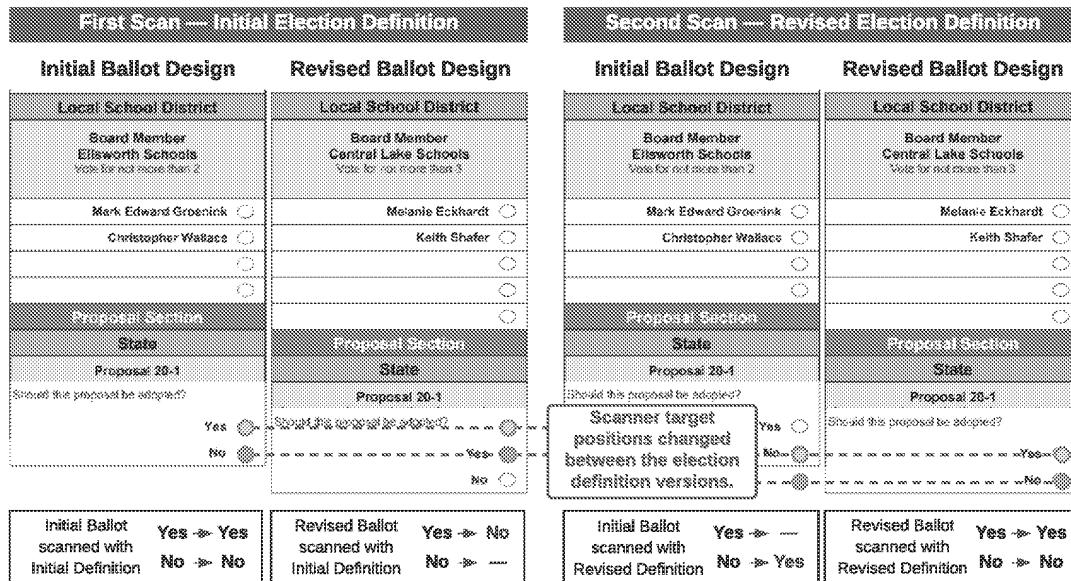


Figure 9: **How State Prop. 20-1 was Scanned in Central Lake Village.** Central Lake scanned ballots twice, once with the initial election definition (*left*) and again with the revised definition (*right*). Some ballots used the initial design and others used the revised design, with targets for Prop. 20-1 shifted down by one row. During each scan, the scanner misinterpreted Prop. 20-1 selections on ballots that did not match the election definition in use (as shown in boxes at bottom).

1. The initial ballot design showed the wrong school board contest (Ellsworth). The scanner incorrectly interpreted these ballots as if they had votes for the Central Lake Schools contest. Votes for Groenink were interpreted as votes for Eckhardt, votes for Wallace were interpreted as votes for Shafer, and votes in the first two write-in blanks were interpreted as write-ins.
2. The position of the voting target for the third write-in blank in the revised ballot design lined up with the position of the darkly shaded “Proposal Section” header on the original ballot. The scanner likely misinterpreted this header as a mark in the third write-in target. The memory card records 10 write-ins cast using the first blank, 4 using the second, and 74 using the third. Since voters usually use earlier write-in blanks before later ones, this strongly suggests that at least 70 ballots used the outdated ballot design.

State Proposal 20-1 was again also affected again during the second scan. This time, voters who used the initial ballot design had their votes miscounted, as shown on the right side of Figure 9. Those who selected “Yes” had the votes discarded, and those who selected “No” were miscounted for “Yes”. Since the poll tapes match the final reported results, these errors have not been corrected.

Choice	Poll Tape		Choice	Ballot Design		Total	Δ
	First	Second		Initial	Revised		
Yes	61	370	Yes	61	$a \approx 359$	420	+50
No	371	69	No	$b \approx 11$	69	80	+11

Table 9: **Remaining Errors in State Prop. 20-1.** An unknown number of voters in Central Lake Village cast ballots using the initial ballot design. Their votes in State Prop. 20-1 were counted incorrectly when the ballots were scanned using the revised election definition. My estimate (*blue*) is that approximately 61 votes are missing from the final reported results: 50 for “Yes” and 11 for “No”.

Estimating the Size of the Error for State Proposal 20-1

The two scan results from Central Lake provide enough information to estimate the number of ballots that used the initial ballot design and the size of the errors.

The first poll tape, based on the initial election definition, showed 61 votes for “Yes” and 371 for “No” from Central Lake Village. Per Figure 9 the “Yes” votes would have been only those marked for “Yes” and using the initial ballot design, while the “No” votes would have been those marked “Yes” using the initial ballot design plus those marked “No” using the revised ballot design. The second poll tape, based on the revised election definition, shows 370 votes for “Yes” and 69 for “No”. Votes counted for “Yes” would have been those marked “Yes” using the revised ballot design plus those marked “No” using the initial ballot design. Those counted for “No” would have been only those marked “No” using the revised ballot design.¹²

We can use these facts to estimate the results without the error. Let a be the number of votes for “Yes” cast using the revised ballot design, and let b be the number for “No” cast using the initial ballot design. Based on the facts above, $a + b \approx 370$. In the rest of Central Lake Township, which was unaffected by the error, “Yes” received 84% of the votes. Under the assumption that Central Lake Village voted for each option in the same proportion:

$$\frac{61 + a}{(61 + a) + (b + 69)} \approx 84\%$$

By simple algebra, $a \approx 359$ and $b \approx 11$. This implies that approximately $61 + 11 = 72$ votes were cast using the initial ballot design, and that approximately $50 + 11 = 61$ votes are missing from the final results for the contest. Table 9 summarizes this analysis.

Since State Proposal 20-1 was decided by a margin of more than 3 million votes, the error could not have affected the outcome.

¹²This implies that the 371 and 370 counts should be equal. The difference is due to one of the three ballots that were not included in the second scan, as discussed in §4.6

4.6 Additional Discrepancies in the Central Lake Scans

Beyond the discrepancies noted above, the poll tapes from the two Central Lake scans show a large number of smaller differences. Many contests have one or two fewer votes in the second scan. One of these differences potentially affected the outcome of a contest. As shown in Figure 10 in the first scan, the Central Lake Village Marihuana Retailer Initiative was tied (and thus defeated), but in the second scan, which became the final result, it passed by a single vote.

My investigation shows that the likely explanation for these differences is that three ballots that were included in the first scan were omitted when the ballots were scanned again. The scanner log from election day, as recorded in the EMS database, shows that 1494 ballots were scanned. Yet the log from the memory card shows that only 1491 ballots were scanned on November 6.

The memory card from the first scan was overwritten to prepare it for the second scan, so the original digital records of the ballots are lost. However, the EMS database contains CVRs derived from the original memory card, in the *CastVoteRecord* table. Using this data, I was able to reconstruct the scanner's interpretation of the omitted ballots.

The CVRs in the EMS record the *EMS's interpretation* of each ballot, which was sometimes affected by the election definition mismatch. Within Central Lake, only ballots from Central Lake Village are affected, and then only particular contests. Selections for the third write-in blank in the school board contest were never recorded. In subsequent contests, selections for the first choice were never recorded, and those for any later choice were assigned to the preceding choice.

(a) Election Day Scan (Nov. 3)
(b) Second Scan (Nov. 6)

A Proposed Initiated Ordinance to Authorize One (1) Marihuana Retailer Establishment Within the Village of Central Lake (1)	
Yes:	262
No:	262
Total Votes:	524

A Proposed Initiated Ordinance to Authorize One (1) Marihuana Retailer Establishment Within the Village of Central Lake (1)	
Yes:	262
No:	261
Total Votes:	523

Figure 10: **Central Lake Village Marihuana Initiative.** In this local contest, the poll tapes differ by one vote—enough to change the outcome. The most likely explanation is that three ballots were somehow omitted during the second scan.

Ballot 1 — Central Lake Township, Precinct 1CENT

President and Vice President of the United States : Donald J. Trump / Michael R. Pence
 United States Senator for State : John James
 Representative in Congress 1st District : Jack Bergman
 Representative in State Legislature 105th District : Ken Borton
 Member of the State Board of Education : Tami Carbone, Michelle A. Frederick
 Regent of the University of Michigan : Sarah Hubbard, Carl Meyers
 Trustee of Michigan State University : Pat O'Keefe, Tonya Schuitmaker
 Governor of Wayne State University : Don Gates
 County Prosecuting Attorney : Write-in
 County Sheriff : Write-in
 County Clerk : Sheryl Guy
 County Treasurer : Sherry A. Comben
 County Register of Deeds : Patty Niepoth
 County Drain Commissioner : Mark Stone
 County Surveyor : Scott Papineau
 County Commissioner 2nd District : Joshua E. Watrous
 Township Supervisor for Central Lake Township : Write-in
 Township Clerk for Central Lake Township : Judy Kosloski
 Township Treasurer for Central Lake Township : Andrew Smith
 Township Trustee for Central Lake Township : Patrick Hanlon, Pat Marshall
 Justice of Supreme Court : Katherine Mary Nepton, Brock Swartzle
 Judge of Court of Appeals 4th District Incumbent Position : Michael J. Kelly, Amy Ronayne Krause
 Judge of Court of Appeals 4th District Non-Incumbent Position : Michelle Rick
 Judge of Circuit Court 13th Circuit Incumbent Position : Kevin A. Elsenheimer
 Board Member for Charlevoix-Emmet Intermediate School District 6 Year Term : Thelma A. Chellis
 State Proposal 20-1 : Yes
 State Proposal 20-2 : Yes

Ballot 2 — Central Lake Township, Precinct 1V

[*No selections.]

Ballot 3 — Central Lake Township, Precinct 1V

Straight Party Ticket : Republican Party
 President and Vice President of the United States : Donald J. Trump / Michael R. Pence
 United States Senator for State : John James
 Representative in Congress 1st District : Jack Bergman
 Member of the State Board of Education : Tami Carbone, Michelle A. Frederick
 Regent of the University of Michigan : Sarah Hubbard, Carl Meyers
 Trustee of Michigan State University : Pat O'Keefe, Tonya Schuitmaker
 County Prosecuting Attorney : James L. Rossiter
 County Sheriff : Daniel S. Bean
 County Clerk : Sheryl Guy
 County Treasurer : Sherry A. Comben
 County Register of Deeds : Patty Niepoth
 County Commissioner 2nd District : Joshua E. Watrous
 Township Supervisor for Central Lake Township : Stanley A. Bean
 Village President for Village of Central Lake : Rob Tyler
 Village Trustee for Village of Central Lake : Bill Chapman
 * School Board Member for Central Lake Schools : Melanie Eckhardt, Keith Shafer
 * State Proposal 20-1 : —
 * State Proposal 20-2 : —
 * A Proposed Initiated Ordinance to Authorize One (1) Marihuana Retailer Establishment Within the Village of Central Lake : No

* indicates contests that are potentially incomplete due to limited data.

Figure 11: **Reconstructed Missing Ballots from Central Lake.** Comparison of data from the EMS and the Central Lake memory card shows that, for unexplained reasons, three ballots that were scanned on Nov. 3 were not included when the ballots were re-scanned on Nov. 6. This figure shows selections registered by the scanner for the omitted ballots. If the Ballot 3 was omitted in error, it likely changed the outcome of the Central Lake Village Marihuana Initiative.

I extracted the CVRs from the first scan from the EMS database and corrected for the election definition mismatch. I also extracted the CVRs from the memory card used in the second scan. Every ballot from the first scan also appears in the second scan, except for three ballots, which I describe below. This further supports the conclusion that three ballots were omitted during the second scan.

Figure 5 shows my reconstruction of the selections from the missing ballots. The first ballot is from Central Lake Precinct 1CENT; the reconstruction is complete, since this precinct was not affected by the election definition mismatch. The second ballot is from Central Lake Village and so would have been affected by the mismatch, but it was recorded by the EMS as blank. Since it is implausible that the voter marked only choices that would have been omitted under the EMS's interpretation, the ballot very likely had no readable selections.

The third ballot is also from Central Lake Village. The contests marked with an asterisk in Figure 5 are potentially missing certain selections due to the election definition mismatch. For the school board contest, the reconstruction is likely correct; neither of the first two write-ins was selected, so the third probably was not either. The EMS did not record selections for State Proposal 20-1 or 20-2, but it is impossible to determine whether this is because the scanner detected a mark for "Yes", which would have been omitted by the EMS, or because there was no detected selection. Finally, the data indicate that the scanner certainly detected a mark for "No" in the Central Lake Village Marihuana Retailer Initiative.¹³

It is likely that these ballots existed on election day, and the data is consistent with the hypothesis that they fully account for the residual differences between the poll tapes from the two scans. Unless they were omitted from the results due to some defect that rendered them invalid, it is likely that the final reported outcome of the Central Lake Village Marihuana Retailer Initiative is incorrect and that the true result is a tie as shown on the election day poll tape.

4.7 Results of the Presidential Hand Count

On December 17, the State Bureau of Elections conducted a county-wide hand-count of the presidential contest [21].

The results [20] showed a loss of 1 vote for Biden, a gain of 12 votes for Trump, and gains of 1 vote for each of three third-party candidates. Although Trump's total changed by more than any other candidate's, it differed from the county's final reported result by only about 0.1%. (Trump lost state-wide by about 2.8%.)

The precinct-level totals closely matched the scanner results. Within individual precincts, Trump and Biden's results changed by at most three votes, except in Star Township, where Biden gained 5 votes and Trump gained 6. Eight precincts showed no change for either Trump or Biden, and six (including Central Lake and Warner) showed no net change for any candidate.

It is not possible from the available data to determine why particular votes changed during the hand count. The scanner CVRs are not linked to individual

¹³While it is possible that there was also a mark for "Yes", which would not have been recorded due to the election definition mismatch, such overvotes are uncommon.

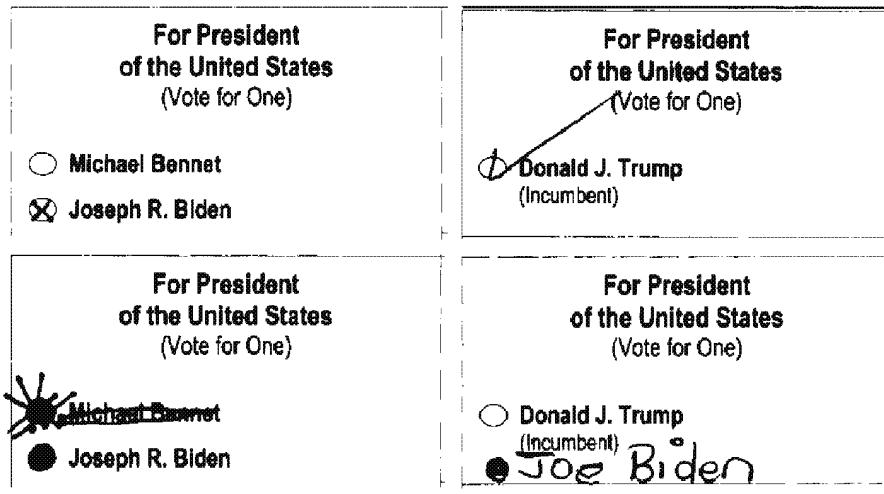


Figure 12: **Examples of Marginal Marks.** Hand counts often produce slightly different results from machine counts due to “marginal marks”, instances where voters fill in voting targets incompletely or otherwise deviate from the ballot instructions. These images, from ballots cast in Georgia’s 2020 partisan primaries, illustrate instances where a human might count the vote differently than would a scanner that simply measures shading within the voting target ovals.

physical ballots, nor are the hand-count results. However, small differences are common when ballots are counted by hand. Sometimes workers counting ballots make mistakes. Humans also interpret some votes differently than optical scanners, which merely sense the intensity of shading within the voting targets. Scanners can misread votes when voters incompletely fill-in voting targets or otherwise deviate from ballot instructions, as illustrated in Figure 12. Such “marginal marks” can cause scanners to fail to count a valid vote, count an invalid vote, or assign a vote to the wrong candidate.

Notably, the hand-count results from Central Lake agree with the results of the township’s second scan, which found 906 votes for Trump, and not the first scan, which found 908 votes for Trump. This may indicate that the three apparently omitted ballots discussed in the previous section were not present during the hand count. (Per my reconstruction in Figure 11, two of the ballots were marked for Trump.) However, it is possible that this is a coincidence, and Trump lost two votes in Central Lake during the hand count for unrelated reasons.

Despite the small differences from the poll tapes, the hand-count provides strong empirical evidence that there are no significant errors in Antrim County’s final reported presidential results.

5 Response to ASOG Report

I have reviewed the “Antrim Michigan Forensics Report—Revised Preliminary Summary, v2”, dated December 13, 2020, prepared by Russell James Ramsland, Jr. of Allied Security Operations Group (the “ASOG Report”, redacted version available at [1]). The report contains an extraordinary number of false, inaccurate, or unsubstantiated statements and conclusions, the most serious of which I refute below. Paragraph numbers that follow refer to the unredacted report.

5.1 Claims Regarding Adjudication

Mr. Ramsland’s central conclusion is that “the Dominion Voting System is intentionally and purposefully designed with inherent errors to create systemic fraud and influence election results” (¶B.2). His reasoning is that the system intentionally generates many errors while scanning ballots in order to cause the images of the ballots to be reviewed by an EMS operator, a process known as “adjudication” during which the votes can be manually edited (¶B.12). This provides an opportunity, Mr. Ramsland believes, for a malicious operator to change votes without being detected. Citing his forensic examination, Mr. Ramsland claims that a “staggering number of votes [in Antrim] required adjudication” (¶B.12), and that “all adjudication log entries for the 2020 election cycle are missing” and must “have been manually removed” (¶B.15).

There are several problems with this theory. First, adjudication occurs after ballots are scanned and poll tapes are printed. In Antrim County, the final reported results match the poll tapes in essentially all cases. Therefore, the final results could not have been altered using adjudication.

Second, Mr. Ramsland mischaracterizes the adjudication process. Dominion’s adjudication system produces detailed logs, which are recorded in the EMS together with the ballot scan and the scanner’s original interpretation, as illustrated in Figure [13]. Far from being an ideal way to cheat without possibility of detection, adjudication creates abundant digital evidence.

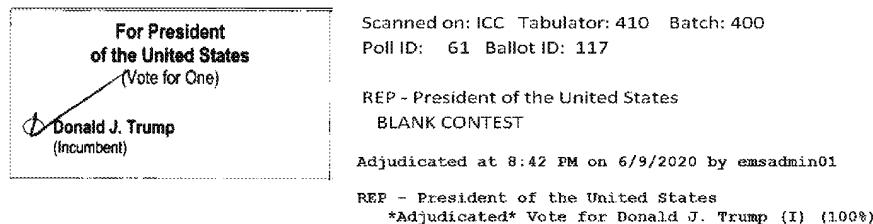


Figure 13: An Adjudicated Vote. These are excerpts from a ballot that was adjudicated after the 2020 presidential primary in Georgia. Dominion’s adjudication system stores the ballot image together with the scanner’s interpretation of the votes and a log of any changes made by the system operator. Adjudication is an optional feature of the Dominion system and was not used in Antrim County.

Third, and fatally, adjudication functionality was not enabled at all in Antrim County during the November 2020 election. The adjudication software application is an optional component of Democracy Suite. Antrim did not purchase it, and my examination of the EMS shows that it was not installed. There are no adjudication logs for the simple reason that adjudication was not used. Moreover, the tabulators were not configured to store ballot images—a necessary precondition for adjudication—and my inspection of the memory cards confirms that no ballot images are present. This means that it would have been impossible to use the adjudication feature even if the software were somehow installed after the election. Far from a “staggering number” of ballots being adjudicated, the actual number was zero. Therefore, Mr. Ramsland’s theories are completely inapplicable to the incident in Antrim County.

5.2 Claims Regarding Errors and Error Rates

Mr. Ramsland claims that Antrim’s scanners exhibited a high rate of errors during ballot processing as a means of enabling systemic fraud (¶¶B.2, B.12). Some errors *did* occur during scanning, as I explained in Section [4] but they affected only specific contests in a small number of precincts, and there is no reason to believe they were intentional. However, Mr. Ramsland is largely referring to others kinds of errors that he believes occurred on the basis of his mistaken interpretations of the forensic evidence.

For instance, the report repeatedly refers repeated to an error rate of 68.05% (¶¶B.6, B.8, J.1, J.3). Mr. Ramsland calculated this percentage from the scanner log for the November 6 rescan in Central Lake, which contains 15,676 lines, 10,667 of which Mr. Ramsland classified as errors. “These errors resulted in overall tabulation errors or ballots being sent to adjudication,” he says, concluding that “[t]his high error rate proves the Dominion Voting System is flawed and does not meet state or federal election laws” (¶B.8).

In actuality, the 68% figure is meaningless. Scanning a single ballot produces a variable number of lines in the log file—ranging from two to dozens—often including many benign warnings or errors. Many other entries and warnings are generated during pre-election testing or while starting or shutting down the machine. This means that the fraction of lines that are errors does not represent a fraction of ballots or votes, the entities for which an error rate would be relevant.

Moreover, the errors in the log file do not mean what Mr. Ramsland purports them to. He claims that “[i]n Central Lake Township there were 1,222 ballots *reversed* out of 1,491 total ballots cast, resulting in an 81.96% rejection rate. All reversed ballots are sent to adjudication for a decision by election personnel” (¶B.10, emphasis in the original). This is referring to log entries like those in Figure [4] that say “Ballot has been reversed”. However, these entries have nothing to do with adjudication. They simply mean that the ballot has been returned to the voter; i.e., the *paper feeding mechanism* has been reversed, as when a vending machine returns a dollar bill that has been misfed. This is a common and benign occurrence. In my experience, it often takes multiple tries to feed a ballot into a scanner, particularly when using a secrecy sleeve like those provided in Michigan.

13441	Nov 06/2020 18:28:22	ScanVote	Ballot 1167 processed successfully.
13448	Nov 06/2020 18:28:22	ScanVote	Total number of ballots = 1292.
13451	Nov 06/2020 18:28:37	ScanVote	Ballot 1167 processed successfully.
13453	Nov 06/2020 18:28:37	ScanVote	Total number of ballots = 1293.
13456	Nov 06/2020 18:28:46	ScanVote Warning	top side start marker (top left corner), RectangleFitting rectW=8 xBottom=5222
13458	Nov 06/2020 18:28:53	ScanVote	Ballot 1167 processed successfully.
13461	Nov 06/2020 18:28:53	ScanVote	Total number of ballots = 1294.
13462	Nov 06/2020 18:29:05	ScanVote Warning	+ error, correlateMarker inputs: xx(0,2190) yy(2303,1643)
13463	Nov 06/2020 18:29:05	ScanVote Warning	+ error, correlateMarker inputs: xx(0,2190) yy(2303,1643)
13464	Nov 06/2020 18:29:05	ScanVote Warning	+ error, correlateMarker inputs: xx(0,2190) yy(2303,1643)
13465	Nov 06/2020 18:29:05	ScanVote Warning	+ error, right marker#44, rectangle height, detected 33, expected 34
13466	Nov 06/2020 18:29:05	ScanVote Warning	+ failed correction, right edge marker#44, pattern match, percent=8.0 px=51482
13467	Nov 06/2020 18:29:05	ScanVote Warning	+ error, right page marker#44 on bottom side not found.
13468	Nov 06/2020 18:29:05	ScanVote Warning	+ error, front page grid problem
13470	Nov 06/2020 18:29:05	ScanVote Warning	+ ballot format or id is unrecognizable.
13471	Nov 06/2020 18:29:07	ScanVote	Ballot has been reversed.
13472	Nov 06/2020 18:29:21	ScanVote	Ballot 1167 processed successfully.
13473	Nov 06/2020 18:29:21	ScanVote	Total number of ballots = 1295.
13475	Nov 06/2020 18:29:37	ScanVote	Ballot 1167 processed successfully.
13476	Nov 06/2020 18:29:37	ScanVote	Total number of ballots = 1296.
13478	Nov 06/2020 18:29:44	ScanVote Warning	+ error, top side barcode horizontal level, slope down: barW=3041 min=3042 max
13479	Nov 06/2020 18:29:44	ScanVote Warning	+ ballot format or id is unrecognizable.
13480	Nov 06/2020 18:29:45	ScanVote	Ballot has been reversed.
13481	Nov 06/2020 18:30:01	ScanVote	Ballot 1167 processed successfully.
13482	Nov 06/2020 18:30:01	ScanVote	Total number of ballots = 1297.
13483	Nov 06/2020 18:38:14	ScanVote	Ballot 1167 processed successfully.
13486	Nov 06/2020 18:39:14	ScanVote	Total number of ballots = 1298.

Figure 14: **Central Lake Scanner Log Entries.** This log excerpt from the Central Lake memory card shows several ballots being processed. The warning messages relate to benign instances where ballots did not feed into the scanner correctly and were ejected (“reversed”) for the voter to try again. This is analogous to a vending machine returning a dollar bill that was inserted incorrectly.

Eleven of 26 lines in Figure 14 are classified by the scanner as warnings, which might result in an “error rate” of 42% by Mr. Ramsland’s methods. However, upon closer inspection, the log merely shows two instances where ballots were misfed and returned to the voter. Both times, ballots were successfully processed a few seconds later, so it is likely that the voters simply tried again.

5.3 Claims Regarding Log Entries

Mr. Ramsland makes several further mistakes in interpreting the election system logs. He states that the scanner log shows that “Divert Options” were selected and claims that this means “all write-in ballots were sent for ‘adjudication’ by a poll worker or election official to process the ballot based on voter ‘intent’. Adjudication files allow a computer operator to decide to whom to award those votes (or to trash them)” (¶J.4). In reality, the divert option simply means that when a voter has selected a write-in, the scanner directs the physical ballot into a separate compartment within the ballot box. This makes it more convenient for a worker to later read the name that was written in. All voter selections, including the presence of a write-in, are processed normally by the scanner and reflected on the poll tape. The setting has nothing to do with electronic adjudication.

Mr. Ramsland also points to scanner log entries that show “Override Options” were enabled for several classes of ballots. He mistakenly claims that these settings “allow[] any operator to change those votes” (¶J.5). “This gives the system operators carte blanche to adjudicate ballots,” he further claims (¶J.6). In actuality, the “Override Options” refer to situations where the scanner warns

a voter that they may have made a mistake when marking their ballot, such as an overvote or undervote. If the override option is enabled, voters are allowed to acknowledge the warnings and cause the scanner to accept their ballots despite the error conditions. These settings have nothing to do with “overriding” voters’ selections, and they do not mean the ballots will be sent to adjudication.

Mr. Ramsland further claims that the scanner log shows that “RCV or Ranked Choice Voting Algorithm was enabled” which “allows the user to apply a weighted numerical value to candidates and change the overall result” (¶J.2). In reality, although some log entries reference the voting system’s RCV feature, they do not indicate that it was enabled. The EMS and memory card data show that RCV was not in use, as do the results of the hand recount of the presidential contest.

Mr. Ramsland claims that on “November 21, 2020, an unauthorized user unsuccessfully attempted to zero out election results” (¶B.17). The only evidence he offers for this assertion is an EMS log file entry that reads “EmsLogger - There is no permission to {0}”, which he claims “is direct proof of an attempt to tamper with evidence” (¶J.8). This is absurd and misleading. A programmer would immediately recognize that {0} is merely a placeholder, in this case one that was intended to be replaced with a description of the attempted action [26]. It has nothing to do with “zeroing” election results.

Citing another error message logged to the EMS, “`XmlException: The ' ' character, hexadecimal value 0x20, cannot be included in a name`”, Mr. Ramsland concludes, “Bottom line is that this is a calibration that rejects the vote” (¶J.8). This is completely baseless. The error refers to a field name in a data structure (an XML entity), which the relevant programming standard does not allow to contain a space. It has no relation to the names of contests or candidates, and there is nothing that suggests the error resulted in a rejected vote.

5.4 Claims Regarding Software Updates

Mr. Ramsland repeatedly mischaracterizes the updates to the scanner election definitions as “software updates” (¶¶B.9, B.18, D.14–17, E.1). Although sometimes referred to as “ballot programming”, election definitions in the Dominion system are not software in the sense of a computer program but rather data files that specify the content and layout of the ballots. In normal operation, they do not change the scanner’s software, although they do affect its behavior. Mr. Ramsland is wrong when he describes Central Lake Township as scanning twice with “different software versions of the operating program to calculate, not tabulate votes” (¶D.16). The scanner used the same software both times, but it was configured using different election definition files.

Elsewhere, Mr. Ramsland seems to confuse ballot definition changes with firmware updates, which *do* change the scanner’s software (¶D.17). Ballot definitions are necessarily changed before every election, but firmware updates are a relatively rare occurrence that typically requires re-certification of the software under U.S. Election Assistance Commission guidelines. There is no evidence that any firmware updates occurred during the 2020 election cycle in Antrim County.

5.5 Claims Regarding Central Lake and Mancelona Townships

The report discusses the differences between the poll tapes from the two scans in Central Lake Township (¶¶D.1–19). It points to three contests where there were large changes to the results: the Central Lake and Ellsworth school board races and State Proposal 20-1. I explained in Section 4 precisely how these changes resulted from revisions to the ballot design in Central Lake Village. No other contests were affected by those revisions.

The report states that the Central Lake Township Clerk told the ASOG team that three ballots that were damaged were not included in the second scan (¶D.3). Elections staff transcribed them onto new ballots, but they were not reflected in the final numbers (¶D.5). As I explained in Section 4.6 the EMS and memory card data indicates that three ballots were omitted during the second scan, so I find this explanation plausible. It further suggests that the final reported outcome of the Central Lake Village Marijuana Retailer Initiative is incorrect, and that the contest should have been determined to be a tie. Why these three ballots were not included in the reported results remains unclear, but the circumstances suggest that it was human error.

The report also discusses Mancelona Township and states that there is no indication that logic and accuracy testing was performed there following the update to the election definition (¶E.2). This is incorrect. The scanner logs from the Mancelona Township memory cards clearly show that this testing was performed. Lines 1–855 of the log from Precinct 1 and lines 1–971 of the log from Precinct 2 indicate that testing was performed from approximately 2–3 p.m. on October 24, the day after the county received the updated election definition. During that time, each log shows 126 or 127 ballots being scanned, a poll tape being printed, and the card being rezeroed. I discussed when logic and accuracy testing was performed and its impact on the incident in Section 4.1.

Mr. Ramsland claims that “the Help America Vote Act, Safe Harbor provides a 90-day period prior to elections where no changes can be made to election systems” (¶D.17), and he says that the use of the revised election definition in Mancelona Township violated this rule, calling it “an election de-certifying event” (¶E.1). In fact, no such rule exists. Moreover, it would not have been possible for Antrim to finalize any of its election definitions 90 days before the November 3 election, since many candidates were not determined until after the results of the August 4 primary election were certified.

5.6 Claims Regarding Venezuela

Mr. Ramsland cites the work of Gustavo Delfino, who used statistical methods to investigate election fraud in Venezuela in the early 2000s. Although Mr. Ramsland writes that “[o]ur investigation into the error rates and results of the Antrim County voting tally reflect the same tactics” (¶B.24), the relevance to Antrim is unclear. Venezuela uses completely different voting technology than Michigan, produced by a different company and based on touch-screen direct-recording electronic voting machines rather than hand-marked paper ballots. To

my knowledge, neither Mr. Ramsland nor Mr. Delfino has performed any credible statistical analysis of the Antrim County results, let alone one that supports the conclusion that there was fraud.

5.7 Claims Regarding Security Problems

Some of the ASOG report's claims about security problems in Antrim County election equipment are correct or based in fact, but Mr. Ramsland draws several incorrect conclusions.

Software Updates The report is correct that the EMS is missing important Windows security updates, leaving it vulnerable to various methods of attack (¶I.2). The system is running Windows 10 version 1607, which was released in 2016, and it appears not to have had any updates installed for at least two years. The antivirus definitions are similarly out of date.

This is a serious security problem. However, Mr. Ramsland is wrong that “[t]here is no way this election management system could have passed tests or have been legally certified” (¶B.16). In fact, missing software updates are frequently an unfortunate consequence of the federal certification process, under which voting system vendors must obtain EAC approval for any changes to election system software, including Windows updates [32]. If there are any security updates that have been approved for the Dominion system, Antrim County should promptly install them. However, installing unapproved updates, even for critical vulnerabilities, would potentially violate the system's certification.

Security Event Log The report is correct that the Windows security event log in the EMS image only contains entries extending back to November 4, 2020, the day after the election (¶B.16). However, the timing appears to be a coincidence. The system is configured so that the maximum size for this log file is 192 MB, and when it grows beyond this size, the oldest entries are automatically removed. Nevertheless, security logs are important sources for forensic investigation and should be retained for as long as they are potentially relevant. Having a fixed maximum size is contrary to best practice.

Network Connectivity The report is correct that Dominion scanners have the ability to be connected to the Internet (¶B.20). Some Michigan jurisdictions use this functionality to transmit preliminary results to their EMSes using wireless modems. Connecting scanners or EMSes to the Internet or other external networks creates significant risks. According to the Michigan Election Security Advisory Commission, “[i]t is possible that unofficial results could be intercepted or manipulated, that the locality's election management system server could be attacked remotely over the network, or that optical scanners could themselves be remotely attacked” [25]. For these reasons, the Commission recommended that jurisdictions discontinue wireless result transmission.

However, Antrim County did not purchase and does not use the Dominion wireless results transmission functionality. Instead, results are returned by physically transporting the memory cards. Based on the EMS event log, it does not appear that the EMS has ever been connected to a network.

Authentication and Access Control The report is correct that the authentication and access control mechanisms on the EMS have serious weaknesses. Antrim workers almost exclusively used a single Windows user account that had full administrative privileges over the computer (¶I.10). This account has the necessary privileges to alter log files and bypass other security controls. For instance, anyone logged into this account has full access to the SQL server databases that run the election, with no additional authentication required (¶I.4). This database access can then be used to circumvent account passwords within the Democracy Suite applications (¶I.5), as I did during my tests.

The report also states that the EMS hard disk was not encrypted (¶I.3). I was unable to find evidence in the disk image to confirm or refute this. If it is true, an attacker with physical access to the computer can bypass the Windows account passwords, install malicious software, and read or change data arbitrarily. Whether or not Antrim County maintains strong physical security for the EMS, disk encryption should be enabled to provide an additional layer of defense.

These problems create real risks to election security and should be promptly mitigated. However, I am not aware of any credible evidence that any security problem was ever exploited against Antrim County's election system. As my analysis shows, the anomalies that occurred in the November 2020 results are fully explained by human error.

6 Conclusion

The November 2020 election incident in Antrim County should serve to remind us that elections are complex and error-prone human processes. They depend on the careful operation of technology and the faithful execution of procedures by people who, like everyone, occasionally make mistakes. It is almost inevitable that some mistakes will occur in an election involving dozens of ballot styles, hundreds of candidates, and many thousands of voters. While we cannot prevent all such human errors, a well designed and administered election system will ensure that when mistakes happen, they will be detected and corrected promptly.

What is striking about the incident in Antrim is not that mistakes happened, but that *so many* mistakes happened. My investigation shows that the incident was initiated when Antrim made last-minute revisions to certain ballot designs. Subsequently, two key human errors directly led to inaccurate results:

- County staff failed to ensure that all ballot scanners were updated with the revised election definition. This corrupted results loaded into the EMS and caused major election-night reporting errors (which are now fully corrected).
- Township staff failed to ensure that all scanned ballots used the revised ballot designs. Ballots that did not match the scanners' configurations were misread, leading to errors in specific precincts and contests (which remain uncorrected).

Antrim could have discovered these problems before bad results were published or deemed official, but several opportunities were missed due to further mistakes:

- Townships failed to notice poll tape errors during pre-election testing.
- Poll workers erased memory cards, making the reporting errors harder to spot.
- County staff did not adequately investigate EMS errors on election night.
- County staff failed to “sanity-check” the initial results before posting them.

To their credit, the county and state quickly understood the technical cause of the major anomalies, though they apparently took longer to grasp the full complexity. However, during the process of correcting the original problems, further mistakes occurred that introduced additional errors:

- County staff neglected to remove bad data before publishing updated results on November 5, again causing widespread reporting errors (later corrected).
- County staff made data entry errors when manually inputting results, affecting more than 2% of reported votes across the county (now fully corrected).
- County canvassers failed to ensure that the reported results matched the poll tapes, allowing data entry errors to become certified results (now corrected).
- For unexplained reasons, three ballots were omitted when Central Lake re-scanned on November 6, likely changing the outcome of the Central Lake Village Marijuana Retailer Initiative (which remains uncorrected).
- County staff omitted part or all of two contests when publishing the final certified results to the county website (which remain uncorrected).

Many of these mistakes would have been harmless individually, but their combined effects undermined safeguards that should have ensured accuracy, leading to election results that were—and, to a lesser extent, still are—incorrect.

Although human error was the root cause of the Antrim County incident, the design of the Dominion software was a contributing factor. All software has room for improvement, and there is no evidence that the Dominion software was deliberately designed to induce errors. However, there were missed opportunities for Dominion to make operator errors less likely or to limit their impact:

- When modifying the ballot designs, the software noted that old ballots and election definitions would be “unusable”. It failed to warn that using them anyway could result in wildly erroneous election results.
- Given this risk, the EMS and scanners could have been engineered to prevent the use of the old ballots and election definitions. They did not and gave no indication when incompatible ballots or election definitions were used.

Defensive software engineering, with a greater emphasis on preventing operator error, could help ensure that problems like those in Antrim do not occur again.

From a security perspective, Antrim County got lucky. I have precisely accounted for all of the known anomalies, and none was the result of a cyberattack. However, several of the election procedures that broke down are important security protections. Just as these mistakes allowed inadvertent errors to slip through, they would have made successfully attacking Antrim’s election system easier. Furthermore, I partially concur with ASOG’s findings that the EMS lacks important security patches, has weak authentication and access control mechanisms, and is vulnerable to compromise by an attacker with physical access. There is no evidence that these problems have ever been exploited in Antrim, but they are serious vulnerabilities that should be mitigated on a priority basis.

The major problems in Antrim were initiated by unusual circumstances (the ballot design changes) that are unlikely to have widely affected other jurisdictions. Nevertheless, the multitude of mistakes and procedural failings that occurred calls into question the adequacy of training and oversight provided to county and local elections staff in Michigan. That there were so many human errors speaks to the extreme pressures that election workers faced last year, in the midst of a global pandemic and a bitterly contested presidential contest. Yet this does not lessen the degree to which the erroneous results were a breach of the public’s trust.

7 Recommendations

On the basis of my investigation, I offer the following recommendations to help safeguard the integrity of future elections:

1. The Bureau of Elections should require counties to perform *end-to-end* pre-election testing, in which memory cards from L&A testing are loaded into the EMS and the results report is checked for accuracy. Such testing would have detected the mismatched election definitions in Antrim County.
2. The Bureau of Elections should revise L&A testing procedures to ensure that testing is repeated after any change to election definitions or ballot designs.
3. The Bureau of Elections should revise county canvassing procedures and training to ensure that reported results in all contests are accurately compared to the results on scanner poll tapes and any discrepancies fully explained.
4. States that do not require canvassers to compare results to poll tapes, as Michigan does, should introduce this form of validation, which provides an important safeguard against accidental or malicious reporting errors.
5. The Bureau of Elections should revise procedures and training to clarify what steps must be taken if absentee voters return ballots that use outdated designs.
6. The Bureau of Elections should revise training materials to include discussion of lessons from the Antrim County incident, including the importance of reviewing results for obvious errors or omissions before making them public.
7. Antrim County should provide additional training for county and township staff concerning the correct operation of the Dominion voting system, including proper procedures for operating the EMS and the polling place equipment.
8. Jurisdictions should retain electronic election records, such as memory cards and EMS data, for as long as physical records. These provide important evidence for investigating (or disproving) problems later discovered or alleged.
9. Jurisdictions should consider enabling the capability of their scanners to save ballot images. These could help resolve questions about the accuracy of results in future incidents, especially if the integrity of the paper trail is questioned.
10. Dominion should revise its documentation to prominently warn that mismatched election definitions could lead to erroneous results.
11. Other voting system vendors should review their equipment to determine whether reporting errors could potentially occur under similar circumstances.
12. Dominion should modify D-Suite to verify that the election definition on any memory card being loaded matches the election definition used by the EMS.
13. Dominion should improve the legibility of scanner poll tapes to ensure that all digits are easily distinguishable during manual entry or canvassing.
14. Dominion should revise documentation and training to emphasize that routine EMS tasks should not be performed from privileged user accounts.
15. Dominion should ensure that customers receive and are instructed to apply all appropriate security updates affecting EMS software components.

16. Dominion should advise customers to enable disk encryption on EMS systems and to increase the retention period of the Windows security event log.
17. The Bureau of Elections should audit the physical security of county EMSes.
18. The Bureau of Elections should require election technology, including EMSes, to promptly receive all appropriate security updates.
19. Counties that transmit scanner results over the Internet or using wireless modems should discontinue these practices, as recommended by the Michigan Election Security Advisory Commission [23].
20. Michigan and other states should expand the use of risk-limiting audits (RLAs) so that they occur in all major contests. RLAs provide a last line of defense against error and fraud and create additional basis for voter confidence.
21. When future election incidents occur, even if they receive less public attention than the events in Antrim County, states should consider performing investigations like this one, to ensure that the problems are well understood and that any lessons are disseminated to help other jurisdictions avoid similar issues.

A Qualifications

My name is J. Alex Halderman. I am Professor of Computer Science and Engineering, Director of the Center for Computer Security and Society, and Director of the Software Systems Laboratory at the University of Michigan in Ann Arbor. I hold a Ph.D. (2009), a master's degree (2005), and a bachelor's degree (2003), *summa cum laude*, in computer science, all from Princeton University. My background, qualifications, and professional affiliations are set forth in my *curriculum vitae*, which is available online at <https://alexhalderman.com/home/halderman-cv.pdf>.

My research focuses on computer security and privacy, with an emphasis on problems that broadly impact society and public policy. Among my areas of research are software security, network security, computer forensics, and election cybersecurity. I have authored more than 90 articles and books, and my work has been cited in more than 11,000 scholarly publications. I have served as a peer-reviewer for more than 35 research conferences and workshops.

I have published numerous peer-reviewed research papers analyzing security problems in electronic voting systems used in U.S. states and in other countries. I have also investigated methods for improving election security, such as efficient techniques for auditing whether computerized election results match paper ballots. I regularly teach courses in computer security, network security, and election cybersecurity at the graduate and undergraduate levels. I am the creator of Securing Digital Democracy, a massive, open, online course about computer security and elections that has attracted more than 20,000 students.

I serve as co-chair of the State of Michigan's Election Security Advisory Commission, by appointment of the Michigan Secretary of State. I have also performed security testing of electronic voting systems for the Secretary of State of California. I have testified before the U.S. Senate Select Committee on Intelligence and before the U.S. House Appropriations Subcommittee on Financial Service and General Government on the subject of cybersecurity and U.S. elections.

I received the John Gideon Award for Election Integrity from the Election Verification Network, the Andrew Carnegie Fellowship, the Alfred P. Sloan Foundation Research Fellowship, the IRTF Applied Networking Research Prize, the Eric Aupperle Innovation Award, the University of Michigan College of Engineering 1938 E Award for teaching and scholarship, and the University of Michigan President's Award for National and State Leadership.

Affirmation

I declare under penalty of the perjury laws of the State of Michigan and the United States that the foregoing is true and correct, and that this report was executed this 23rd day of March, 2021.

J. Alex Halderman

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